October 1968

Effects of Rainfall and Drop Size on the M564 Fuze

FINAL REPORT

ON

U. S. Army Contract
DAAG 11-68-C-1342

Prepared by

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ERRATA

During the review of this report, it was brought to the attention of the authors that the sensitive portion of the fuze should have been 12 mm in diameter instead of the 15 mm that was used throughout the report.

Since this correction enters all of the calculations as to the expected number of drop encounters a correction of this area requires that all expected encounters should be multiplied by 0.64.

This change does not effect the conclusion that the total number of encounters appears to be detonating the fuze. Using the corrected sensitive area, about 100 drop encounters are required for detonation instead of the 150 mentioned in the conclusions.

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ABSTRACT

The results of test firings of an M564 fuze in tropical rains are presented. In this report, various rainfall conditions are examined. It is tentatively concluded that the total number of raindrops encountered is more important than the size of the raindrops.

All of the modified fuzes successfully penetrated rainfall and detonated properly in the impact area.

The average drop size distributions from a 1129 m^3 sample for the tropical Panama rains are very similar to the drop size distributions obtained in thunderstorms at Miami, Florida and Bogar, Indonesia.

FOREWARD

This report summarizes work which was done in the Panama Canal Zone by Dr. E. A. Mueller and Mr. Arthur Sims of the Illinois State Water Survey at the University of Illinois for the U. S. Army Frankford Arsenal, under Contract No. DAAG 11-6 8-C-1342, under the technical surveillance of Messrs. David Askin and John F. Sikra of Frankford Arsenal.

The authors desire to acknowledge the U. S. Army Tropical Test Center for providing facilities and aid in the data collection. In particular the direct aid afforded by S/SGT Ramon Colon - Pomales was greatly appreciated. In addition the aid given by Dr. Leonard Teitel of Frankford Arsenal in locating and installing the equipment is gratefully acknowledged.

The raingages were serviced by a U. S. Army Meteorological Team and some of the raindrop camera data collected were gather by this group.

INTRODUCTION

An experiment was conducted in Panama during June and July of 1968 to determine the rain conditions which lead to premature detonation of the M564 fuze, and secondly to verify that a modified fuze would successfully penetrate tropical rains without premature detonation.

Meteorological equipment to perform this task consisted of 12 raingages and a raindrop camera. The raingages were weighing bucket recording gages with 6-hour chart speed. Six of the raingages were supplied by the University of Illinois. These gages were furnished with 12-inch tops instead of the standard 8-inch top. The increased top size permits more accurate measurements of rain amounts as the vertical scale is magnified 2.5 times. The 12 raingages were located along the firing line in accordance with figure 1. The charts from these raingages permitted the determination of the rainfall rate along the firing line. The raindrop camera determines the raindrop size spectra as a function of rainfall rate. During times of the artillery firing the raindrop camera was operated at 28 frames/minute to obtain a sample which is as representative as possible. During non-firing times the camera rate was reduced to 7 frames/minute which represents one cubic meter sample volume.

The analysis contained within this report was obtained from the raingage data, the drop camera data, and the shooting record data which was provided by the Army. The shooting record data consisted of the time of firing, the type of fuze which was fired, and either the distance to premature burst or the information that the projectile successfully detonated in the impact area. The distance to the early burst was determined by a sound ranging technique. A number of microphones recorded the speed of sound, initial projectile velocity and the time of the returning sound from detonation. Using these measurements the distance to the detonation could be determined.

In Appendix A, a reproduction of the firing tables is presented along with the average rainfall rate, the liquid water content, and expected numbers of drops encountered. These numbers are computed for the distance between the gun and the point of detonation.

SUMMARY OF DROP DATA

From the operation of the drop camera at the Piña Range location, 1290 samples of 1 m^3 each were obtained between June 27-July 20. These have all been measured. A large portion of these samples were taken at a sampling rate of 28 frames/minute or 4 m^3/minute. These data required the use of 25 rolls of 70-mm film, 100 ft/roll.

After July 20, the drop camera was operated by Army personnel at Battery Mackenzie. At the time of this writing, 24 rolls of film from that location have been received. All the Battery Mackenzie data were taken at a data rate of 7 frames/minute or 1 m^3/minute. Approximately 260 samples of these data have been measured. It is estimated that approximately 1250 samples are yet to be measured. Included in this estimate are 6 rolls which were received since the film processing equipment was shipped to the Canal Zone. These will be processed at the end of the November experiments. The Battery Mackenzie data on hand will be measured until data from the new experiments are received.

RAINGAGE ANALYSIS

The raingage charts were digitized by a semi-automatic chart reader (Autotrol Model 3400). The IBM cards which resulted from this process were processed by an IBM 7094 computer to provide 5-minute rainfall rates. Initially, it had been hoped to process the raingage charts for 1 minute rainfall rates; however, timing on the raingage charts were found to be inconsistent when analyzed on a one minute basis. Times on and off were apparently logged only to the nearest 5 minutes. The 5-minute rates were used except for the maximum rate column in tables 1 through 10. The maximum rate is the maximum 1-minute rate during each rain period.

The length of records at various gages are different due to different installation dates as well as occasional gage malfunctions. In addition each gage was analyzed separately with respect to the time of a storm. Thus in some instances one storm at one gage may be represented by time rain periods at other gages. Raingage 1 was installed for the longest period and did not malfunction.

TABLE 1. Raingage Storm Summaries from Gage No. 1

GAGE NUMBER 1

Date	Time Begin LST	Time End LST	Total Amount Inches	Max 5-Min Amount Inches	Max Rate Inches/Hour	Dur Hours
6/24	1355	1848	0.33	0.04	0.60	4.9
6/25	1500	1803	1.05	0.18	4.20	3.1
6/27	1543	1644	0.28	0.11	2.10	1.0
6/29	0555	0642	0.05	0.01	0.19	0.8
6/29	1632	1746	0.28	0.07	1.80	1.2
6/30	1155	1547	1.73	0.22	3.00	3.9
6/30	1844	2004	0.03	0.01	0.05	1.3
6/30	2111	2146	0.06	0.02	0.30	0.6
7/ 1	0549	0633	0.09	0.03	1.20	0.7
7/ 1	0806	0814	0.13	0.11	2.40	0.1
7/ 2	1111	1220	0.03	0.01	0.15	1.2
7/ 2	1536	1558	0.13	0.05	0.60	0.4
7/ 4	1643	1733	0.02	0.01	0.12	0.8
7/ 5	1302	1557	0.20	0.05	1.20	2.9
7/ 7	0950	1542	0.09	0.02	0.19	5.9
7/ 8	0137	0434	0.16	0.03	0.60	3.0
7/ 8	2008	0508	0.07	0.02	0.39	9.0
7/ 9	1243	1603	0.09	0.02	0.60	3.3
7/ 9	2051	2313	0.09	0.04	0.60	2.4
7/10	1939	2001	0.06	0.03	0.60	0.4
7/11	0541	0858	0.43	0.09	1.50	3.3
7/14	0152	0329	0.70	0.16	3.00	1.6
7/15	1204	1257	0.02	0.01	0.08	0.9
7/15	1930	0101	2.79	0.57	9.80	5.5
7/16	0958	1040	0.04	0.02	0.60	0.7
7/16	1638	2030	0.19	0.02	0.60	3.9
7/17	0611	0658	0.03	0.01	0.19	0.8

TABLE 2. Raingage Storm Summaries from Gage No. 2

GAGE NUMBER 2

Date	Time Begin LST	Time End LST	Total Amount Inches	Max 5-Min Amount Inches	Max Rate Inches/Hour	Dur Hours
6/24	1350	1733	0.30	0.05	0.60	3.7
7/ 4	1706	1906	0.03	0.01	0.05	2.0
7/ 5	0857	1252	0.22	0.10	1.20	3.9
7/ 7	0737	0830	0.07	0.02	0.60	0.9
7/ 9	1225	1555	0.11	0.02	0.60	3.5
7/ 9	2055	2309	0.09	0.04	0.90	2.2
7/10	1641	1703	0.06	0.03	0.39	0.4
7/11	0456	0903	0.43	0.09	1.50	4.1
7/14	0155	0324	0.70	0.16	2.10	1.5
7/15	1230	1320	0.01	0.01	0.08	0.8
7/15	1939	0102	2.79	0.44	6.60	5.4
7/16	1016	1124	0.04	0.01	0.60	1.1
7/16	1611	1952	0.18	0.02	0.30	3.7
7/17	0516	0602	0.03	0.02	0.60	0.8
7/19	0332	0641	0.57	0.14	3.00	3.2

TABLE 3. Raingage Storm Summaries from Gage No. 3

GAGE NUMBER 3

Date	Time Begin LST	Time End LST	Total Amount Inches	Max 5-Min Amount Inches	Max Rate Inches/Hour	Dur Hours
6/29	1636	1743	0.27	0.08	2.40	1.1
6/30	1034	1650	1.69	0.23	3.60	6.3
6/30	2105	2200	0.09	0.02	0.30	0.9
7/ 1	0049	0058	0.02	0.01	0.19	0.2
7/ 1	0553	0630	0.07	0.05	2.40	0.6
7/ 1	0807	0815	0.09	0.06	1.80	0.1
7/ 2	1117	1201	0.04	0.01	0.30	0.7
7/ 2	1457	1527	0.12	0.05	1.20	0.5
7/ 4	1637	1805	0.03	0.01	0.09	1.5
7/ 5	1301	1538	0.20	0.05	0.60	2.6
7/ 7	0952	1506	0.07	0.01	0.19	5.2
7/ 8	0136	0438	0.17	0.03	0.79	3.0
7/ 8	2009	0532	0.08	0.02	0.30	9.4
7/ 9	1221	1636	0.10	0.02	0.24	4.3
7/ 9	2030	2303	0.11	0.04	0.60	2.6
7/10	1937	2000	0.08	0.05	1.20	0.4
7/11	0538	0911	0.43	0.07	1.50	3.6
7/14	0149	0228	0.28	0.12	2.10	0.7
7/15	1219	1315	0.02	0.01	0.06	0.9
7/15	1909	0101	2.77	0.47	5.40	5.9
7/16	1022	1102	0.02	0.02	0.30	0.7
7/16	1546	1952	0.17	0.02	0.30	4.1
7/17	0514	0600	0.03	0.01	0.60	0.8
7/19	0332	0620	0.44	0.11	1.80	2.8

TABLE 4. Raingage Storm Summaries from Gage No. 4

GAGE NUMBER 4

Date	Time Begin LST	Time End LST	Total Amount Inches	Max 5-Min Amount Inches	Max Rate Inches/Hour	Dur Hours
6/29	1659	1749	0.25	0.06	0.90	0.8
6/30	1038	0113	1.83	0.28	5.40	14.6
7/ 1	0553	0634	0.08	0.03	1.20	0.7
7/ 1	0803	0815	0.08	0.06	1.80	0.2
7/ 2	1133	1610	0.20	0.05	0.72	4.6
7/ 4	1628	1901	0.05	0.02	0.30	2.6
7/ 5	1301	1504	0.20	0.05	0.60	2.1
7/ 7	0950	1458	0.13	0.01	0.30	5.1
7/ 8	0137	0646	0.23	0.04	1.80	5.2
7/ 9	0042	0701	0.12	0.02	0.39	6.3
7/ 9	1236	1644	0.12	0.02	0.24	4.1
7/ 9	2051	2304	0.09	0.02	0.60	2.2
7/10	1933	2003	0.10	0.06	1.20	0.5
7/11	0540	0849	0.41	0.06	0.90	3.2
7/14	0115	0330	0.81	0.22	5.40	2.3
7/15	1229	1304	0.03	0.01	0.08	0.6
7/15	1933	0101	2.77	0.45	6.60	5.5
7/16	1006	1117	0.06	0.02	0.19	1.2
7/16	1613	1953	0.18	0.02	0.19	3.7
7/17	0522	0610	0.04	0.01	0.13	0.8
7/19	0329	0605	0.56	0.15	3.00	2.6

TABLE 5. Raingage Storm Summaries from Gage No. 5

GAGE NUMBER 5

Date	Time Begin LST	Time End LST	Total Amount Inches	Max 5-Min Amount Inches	Max Rate Inches/Hour	Dur Hours
6/29	2109	2138	0.21	0.06	1.20	0.5
6/30	1031	1625	1.57	0.29	6.60	5.9
6/30	2117	2148	0.10	0.03	0.39	0.5
7/ 1	0554	0631	0.10	0.03	1.80	0.6
7/ 1	0808	0822	0.06	0.04	0.39	0.2
7/ 2	1156	1553	0.14	0.03	0.60	4.0
7/ 4	1623	1702	0.03	0.01	0.17	0.7
7/ 5	1209	1753	0.20	0.03	0.60	5.7
7/ 7	0950	1201	0.06	0.01	0.09	2.2
7/ 8	0136	0453	0.18	0.03	0.60	3.3
7/ 9	0038	0507	0.08	0.01	0.30	4.5
7/ 9	1230	1553	0.10	0.02	0.16	3.4
7/ 9	2045	2'316	0.11	0.02	0.19	2.5
7/14	0146	0445	0.82	0.21	5.40	3.0
7/15	1217	1309	0.03	0.01	0.07	0.9
7/15	1940	0111	2.45	0.43	7.20	5.5
7/16	1012	1050	0.06	0.03	0.60	0.6
7/16	1616	1944	0.18	0.03	0.60	3.5
7/17	0535	0601	0.05	0.02	0.19	0.4
7/19	0316	0554	0.53	0.13	2.10	2.6

TABLE 6. Raingage Storm Summaries from Gage No. 6

GAGE NUMBER 6

Date	Time Begin LST	Time End LST	Total Amount Inches	Max 5-Min Amount Inches	Max Rate Inches/Hour	Dur Hours
6/29	2130	2158	0.21	0.06	0.90	0.5
6/30	1350	0317	1.35	0.19	2.40	13.5
7/ 1	0556	0645	0.09	0.04	1.20	0.8
7/ 1	0810	0825	0.10	0.05	0.60	0.3
7/ 2	1134	1747	0.21	0.03	0.39	6.2
7/ 4	1623	1825	0.02	0.01	0.04	2.0
7/ 5	1118	1431	0.11	0.02	0.25	3.2
7/ 7	0958	1308	0.06	0.01	0.15	3.2
7/ 8	0144	0701	0.20	0.03	0.60	5.3
7/ 9	0237	0707	0.07	0.01	0.19	4.5
7/ 9	1016	1327	0.09	0.02	0.18	3.2
7/ 9	2050	2300	0.05	0.01	0.09	2.2
7/10	1931	2003	0.09	0.03	0.45	0.5
7/11	0547	1156	0.30	0.04	0.79	6.2
7/14	0204	0523	0.72	0.23	4.20	3.3
7/15	1229	1245	0.02	0.01	0.17	0.3
7/15	1919	0058	2.39	0.48	10.20	5.7
7/16	1020	1045	0.06	0.03	0.39	0.4
7/16	1724	2007	0.14	0.02	0.17	2.7
7/17	0535	0603	0.03	0.01	0.17	0.5
7/19	0313	0457	0.45	0.10	1.50	1.1

TABLE 7. Raingage Storm Summaries from Gage No. 7

GAGE NUMBER 7

Date	Time Begin LST	Time End LST	Total Amount Inches	Max 5-Min Amount Inches	Max Rate Inches/Hour	Dur Hours
6/30	1337	0822	1.58	0.14	3.00	18.8
7/ 2	1125	1555	0.14	0.04	0.39	4.5
7/ 4	1642	1833	0.02	0.01	0.09	1.9
7/ 5	1139	1754	0.18	0.05	0.60	6.3
7/ 7	0949	1538	0.10	0.01	0.30	5.8
7/ 8	0126	0656	0.17	0.02	0.60	5.5
7/ 8	2012	0544	0.07	0.01	0.15	9.5
7/10	1928	1957	0.09	0.05	1.20	0.5
7/11	0514	1208	0.37	0.05	0.90	6.9
7/12	1112	2015	0.24	0.03	0.60	9.1
7/14	0149	0229	0.26	0.13	3.60	0.7
7/15	1237	1500	0.03	0.01	0.60	2.4
7/15	1922	0109	2.34	0.37	4.80	5.8
7/16	1022	1146	0.07	0.04	0.60	1.4
7/16	1619	2025	0.15	0.02	0.15	4.1
7/17	0536	0658	0.05	0.01	0.19	1.4
7/19	0323	0624	0.50	0.12	2.10	3.0

TABLE 8. Raingage Storm Summaries from Gage No. 8

GAGE NUMBER 8

Date	Time Begin LST	Time End LST	Total Amount Inches	Max 5-Min Amount Inches	Max Gage Inches/Hour	Dur Hours
6/30	1345	1847	0.98	0.11	2.40	5.0
6/30	2058	0048	0.10	0.02	0.30	3.8
7/1	0324	0828	0.58	0.24'	3.60	5.1
7/ 2	1130	1635	0.13	0.02	0.39	5.1
7/ 5	1221	1707	0.20	0.06	1.80	4.8
7/ 7	0948	1429	0.08	0.01	0.15	4.7
7/ 8	0121	0731	0.18	0.02	0.60	6.2
7/ 8	2010	0526	0.07	0.01	0.60	9.3
7/ 9	1242	1651	0.07	0.01	0.17	4.2
7/ 9	2038	2333	0.09	0.02	0.60	2.9
7/10	1939	2011	0.08	0.04	0.60	0.5
7/11	0532	0917	0.33	0.05	0.90	3.8
7/12	1630	1854	0.10	0.01	0.30	2.4
7/14	0135	0431	0.63	0.15	3.00	2.9
7/15	1222	1304	0.02	0.01	0.08	0.7
7/15	1651	0114	2.26	0.39	6.60	8.4
7/16	1024	1128	0.09	0.03	0.60	1.1
7/16	1620	2002	0.13	0.01	0.15	3.7
7/17	0521	0555	0.03	0.01	0.09	0.6
7/19	0314	0627	0.49	0.13	3.00	3.2

TABLE 9. Raingage Storm Summaries from Gage No. 9

GAGE NUMBER 9

Date	Time Begin LST	Time End LST	Total Amount Inches	Max 5-Min Amount Inches	Max Rate Inches/Hour	Dur Hours
7/ 2	1129	1641	0.11	0.03	0.60	5.2
7/ 4	1642	1855	0.01	0.01	0.01	2.2
7/ 5	1255	1815	0.17	0.07	1.80	5.3
7/ 7	0929	1428	0.06	0.01	0.09	5.0
7/ 8	0126	0746	0.17	0.02	0.60	6.3
7/ 9	1246	1723	0.07	0.01	0.09	4.6
7/ 9	2041	2359	0.08	0.02	0.30	3.3
7/10	1924	1956	0.09	0.07	1.20	0.5
7/11	0519	1138	0.32	0.05	2.40	6.3
7/12	1111	1947	0.28	0.08	1.80	8.6
7/14	0119	0431	0.55	0.22	3.60	3.2
7/15	1236	1305	0.00	0.00	0.00	0.5
7/15	1652	0101	1.95	0.42	6.60	8.2
7/16	1025	1141	0.09	0.04	0.60	1.3
7/16	1753	1955	0.14	0.02	0.30	2.0
7/17	0533	0646	0.04	0.01	0.15	1.2
7/19	0312	0643	0.51	0.12	2.40	3.5

TABLE 10. Raingage Storm Summaries from Gage No. 10

GAGE NUMBER 10

Date	Time Begin LST	Time End LST	Total Amount Inches	Max 5-Min Amount Inches	Max Rate Inches/Hour	Dur Hours
7/ 9	1140	1329	0.05	0.01	0.07	1.8
7/ 9	2034	2259	0.11	0.03	1.20	2.4
7/10	1945	2021	0.06	0.04	1.20	0.6
7/11	0545	1211	0.50	0.08	1.20	6.4
7/12	1108	1904	0.25	0.03	0.60	7.9
7/14	0200	0316	0.54	0.20	4.20	1.3
7/15	1938	0109	1.92	0.40	5.70	5.5
7/16	1022	1123	0.15	0.05	0.75	1.0
7/16	1805	1951	0.14	0.02	0.15	1.8
7/17	0535	0601	0.03	0.01	0.15	0.4
7/19	0311	0636	0.54	0.15	2.40	3.4

As an example of the variability of the rainfall rates, the July 15 storm had maximum rates from 10.20 inches/hour at gage 6 to as low as 5.40 inches/hour at gage 3.

During this 30-day period there were three storms with a total rainfall greater than 1.0 inches, and two of these occurred before the gun was in place and ready for firing. From June 24 to July 17, there were 63.6 hours of rainfall at the gun site. However, a surprisingly large amount of this time was in light rainfall. During this same period there was a total of 250 minutes during which the rainfall rate exceeds 0.6 inches/hour.

ANALYSIS OF PREMATURE DETONATIONS

Sensitivity of fuzes to average rainfall rate

Average rainfall rates throughout the range were calculated by averaging the rates from each of the raingages. Each raingage was assumed of equal weight despite some differences in spacings. The rainfall rates for this portion of the study were based on 5-minute amounts.

The set of data representing the standard M564 fuze and the delay fuze was then ranked by average rainfall rate and a cumulative curve of rounds versus rate was prepared (see figure 2). A total of 51 rounds was fired which went to the impact area. Five of these rounds penetrated rain greater than 1 inch/hour. A smoothing curve was passed through the points by eye and is shown on the figure.

Likewise, the set of data representing the premature firing of standard rounds was prepared and is shown in figure 3. Twenty-two of the rounds burst early in rainfall rates of greater than 1 inch/hour. Thus, 22 of 27, or 81%, of the rounds burst prematurely in rates greater than 1 inch/hour.

From the smoothed curves, the expected number of penetrations and early bursts in an interval were computed. Table 11 shows this calculation. Figure 4 is the plot of the expected percentage of early bursts as a function of rainfall rate.

There were 18 rounds fired in a rainfall rate greater than 1 inch/hour with the steel-tipped urethane (STU) or the urethane (U) rain cap on the fuze.

TABLE 11. Calculations of Percentage Early Bursts from Average Curves

R Rate (in/hr)	I Cum. No. into Impact	ΔI	EB Cum. No. of Prematures	ΔEB	Percentage
.45	33				
		3.9			
.56	36.9		1		
		3.1		2	39
.71	40		3		
		2.8		1.8	39
.89	42.8		4.8		
		2.4		1.7	41
1.1	45.2		6.5		
		1.8		2.0	53
1.4	47		8.5		
		.8		2.3	70
1.8	47.8		10.8		
		.7		2.5	78
2.25	48.5		13.3		
		.3		3.0	90
2.8	48.8		16.3		
		.3		3.5	92
3.5	49.1		19.8		
		.2		4.7	96
4.2	49.3		24.5		

None of these rounds fired prematurely. The highest average rate which was penetrated by a standard round was 3 inches/hour. There were five STU or U fuzes successfully fired through a rate greater than 3 inches/hour.

Another means of evaluating the effectiveness of the STU/U fuze is to consider the probability that the 18 rounds which successfully penetrated the rain were just a result of sampling error. If the same probability is assumed for the STU/U modified fuzes as for the standard M564 fuze, the probability of 18 rounds penetrating the rain completely would be 6×10^{-14}. Certainly this is highly unlikely.

To further show that there was no bias in the rain rates in which the different fuzes were fired, figure 5 was prepared. In this figure the crosses represent rounds using the standard fuze and circles represent rounds using the STU/U fuzes. These curves indicated that no serious differences in the rainfall rates during firing exist between the standard and modified fuzes. At rates greater than 1 inch/hour, more standards were fired than modified (26 vs. 18), but since the highest rate was nearly the same in both cases, and since none of the 18 modified fuzes fired prematurely, this would not appear to bias the data unduly.

<u>Sensitivity of fuzes to raindrop sizes</u>

In an attempt to determine whether the standard fuzes were firing prematurely by impacting on raindrops of a critical size, the following analysis was performed.

The average drop size spectra as a function of rainfall rate was used to determine the average number of drops greater than 3.0, 3.5, 4.0, and 4.5 mm as a function of rate. For each round that was fired, the rainfall rate at each raingage along the firing line was determined. From these raingage rates, a drop size spectrum was inferred.

The actual cross sectional area of the sensitive portion of the standard fuze is not known. Furthermore, and more appropriately, a collision cross section which takes into consideration the tendency for the raindrop to move laterally with respect to the trajectory of the projectile should be used. However, as a first approximation a sensitive area of a circle 15 mm in diameter was used to predict the probable collisions of the raindrops with the fuze.

The expected number of collisions was calculated under the following conditions:

a) Each raingage rate was representative of a distance equal to the distance between the center points of the adjacent gages and the gage under examination.

b) The average drop size spectra is predicted by the raingage rate.

c) The sensitive area of the fuse is 1.77×10^{-4} m^2.

A surprisingly great variation between raingage rates was frequently encountered. Thus, to assume the rate is invariant for 1/2 the distance between gages, and then discontinuously changes to a new and greatly different rate is obviously incorrect. A better approximation would be to assume the rainfall rate varies linearly between raingages. This method requires considerably more labor and since as will be seen, there is little sensitivity to drop size, it is not profitable to refine the analysis to this degree.

The second assumption is harder to evaluate. In the past, average distributions have been justified by noting the amount of scatter in the individual rainfall rates included in the average. For this analysis where only the larger drops are under consideration, it is noted that there were instances where relatively high rates were accompanied by an absence of large drops in the sample volume. Thus, it would appear that the variance of the numbers of large drops may be greater than the range of rainfall rates would indicate. Nonetheless, this assumption is considered to be the best available if any estimate of drop size sensitivity is to be recognized.

Under these assumptions, the expected number of drops encountered by the sensitive area of the fuze was calculated. The length of the trajectory for the premature rounds was the preliminary sound ranging distances, and for the impact area was chosen as 1850 m.

After the expected number of drop collision for each round was calculated, the cumulative frequency distribution of occurrences versus expected number of drops was plotted. These are shown in figures 6, 7, 8, and 9 for the premature rounds, and in figures 10, 11, 12, and 13 for the standard rounds into impact.

Since the number of rounds fired was small statistically, these cumulative frequency graphs were used to smooth the data. From the smoothing curve drawn th rough the resulting data points, the relative frequency of early bursts to total rounds fired was calculated at a number of points along the curves. These curves are shown in figures 14, 15, 16, and 17. Despite the smoothing which was introduced, a large amount of scatter in the resulting curves is still apparent.

If there was a critical number of impacts which produced premature detonation, one would expect the curve of percentage of early bursts versus number to exhibit a stretched "S" shape. That is, if the expected number of encounters was less than the threshold number, the percentage of early bursts should be quite low. Conversely, when the expected number of drop encounters was much greater than the threshold level, the percentage should be large.

It is apparent from figure 17, that probability of early burst of 0.5 occurs when the expected number of encounters with very large drops is less than 0.1. Thus, it is unlikely that the premature firing is produced by the very large drops. A fitting line is sketched on this figure. It indicates a tendency for a reduction in probability of early bursts as the expected number of encounters increases between 0.15 and 0.3. This observation is probably an artifact introduced by the smoothing applied to the cumulative distributions. In this region there were no observations of rounds into the impact area. In fact, only 4 rounds penetrated to the impact area when the expected number of collisions was greater than 0.11. Unfortunately, the occurrence of large drops occurs concurrently with large numbers of small drops and also with large values of liquid water concentrations. Thus, separation of the effects of the large drops is complicated by the simultaneous variation of the remaining parameters.

Essentially the same comments apply in lesser degree to the other figures for drops larger than 3.0, 3.5, and 4.0 mm. In all cases considerable s catter remains.

Even on the 3.0 mm case, there was one premature firing recorded in which the rainfall rate throughout the range would have predicted no encounters with medium and large drops. Of course with the variability of rainfall as large as it is, there may have indeed been an encounter.

The conclusion which can be drawn from these figures is that there does not appear to be a threshold of drop size which produces premature firing.

Sensitivity of fuzes to total number of drops

In a manner analogous to the analysis for drop size sensitivity, frequency curves for the total number of drop encounters were prepared. The results are shown in figures 18, 19, and 20. Figure 20 shows a large amount of scatter around the lower values. This is most likely an artifact of the analysis. The smoothing curves shown in figures 18 and 19 do not match the data well in the small encounter region. Furthermore, the small size of the sample in this region contributes to the scatter when ratios are taken.

The probability of premature detonation increases rapidly when the expected number of collisions is about 125 to 150 drops.

If it is supposed that 150 drops are required to detonate the fuze, the distance as a function of rainfall rate can be determined. Figure 21 shows the relationship between rate and distance as a function of probability of early detonation. These results can be interpreted as follows; if the rainfall rate is 10 mm/hr, the projectile travels 3 km before the probability of detonation is 0.5, but by the time it has traveled 7 km it has a probability of detonating of 0.9.

It should be noted that this figure represents an extrapolation of the results of the experiment. It assumes that a drop encounter when the projectile has traveled a long distance is as effective in producing premature detonation as an encounter at short ranges. Since the projectile slows down considerably as it proceeds down range, the forces of impact are undoubtedly reduced. Furthermore, it may be that the individual encounters are less important than two or more encounters in a time sufficiently short that the fuze cover cannot mechanically return to a neutral position. Either of these effects, would make the extrapolation for figure 21 doubtful. More data over longer ranges will be necessary to have confidence in this figure. These data should be available from the November tests.

AVERAGE RAINDROP SIZE DISTRIBUTIONS

Average distributions were calculated from the 1129 1-m^3 distributions of data collected through July 15. The 1-m^3 distributions were sorted in ascending order of rainfall rate. These were then divided into 12 groups.

For each group, the number of drops of each size increment was averaged. The resulting average distributions were then used to calculate R, Z, Q, L, DL, and NT. These parameters are defined and units for them are given in table 12.

The average distributions are tabulated in table 13. Each distribution is preceded by the parameters calculated from it, beginning with R, the rainfall rate. NS in these tabulations is the number of 1-m^3 samples included in the average distribution. The drop distribution follows NS, and begins with the number of 0.5-mm drops, and continues in 0.1-mm increments to 7.9 mm. Drop sizes from 0.5 mm through 1.1 mm are indicated in the first line, from 1.2 mm through 2.6 mm in the second line, 2.7 mm through 4.3 mm in the third line, 4.4 mm through 6.6 mm in the fourth line, and from 6.7 mm through 7.9 mm in the fifth line. The first two lines are always present; the remaining lines are used only as far as necessary to report all non-zero concentrations.

Six of these average distributions are shown as a family of curves in figure 22. These are "by eye" fittings to the points plotted from the tabulations, and are slightly smoothed, particularly in the large diameter end of the distributions. These curves show the general trends of the distribution with changes in rainfall rate. The mode of the distribution tends to increase with rate until the highest two curves, then becomes slightly bi-modal. Some of the 1-m3 high rate distributions are even more bi-modal. This characteristic has also been noted in rains at Miami, Florida.

CONCLUSIONS AND RECOMMENDATIONS

Overall the test program was successful. The successful penetration of all of the modified M564 fuzes in rainfall rates, which were as high as 9.80 inches/hour at one station, shows that the modification is unquestionably adequate for the 105 mm Howitzer operations.

The second major objective of this research was to determine what parameter of the rainfall is most highly correlated with the premature firing of the standard fuze. In our opinion, the results support the contention that the total number of droplets encountered are responsible for the early

TABLE 12. Definitions of Terms and Units

Symbol	Definition	Units
R	Rainfall rate	$mm\ hr^{-1}$
Z	Radar reflectivity	$mm^6 m^{-3}$
Q	Attenuation cross section	$mm^2 m^{-3}$
L	Liquid water content of rain	$g\,m^{-3}$
DL	Median volume diameter	mm
NT	Total concentration	m^{-3}

Table 13 Average raindrop distributions for data taken at the Plña Range, Canal Zone,
June 27 to July 19, 1968.

```
R=    .2  Z=8.00E 01  Q=   1  L=  .01  DL=1.4  NT=  12.45  NS= 85      .06    .06    .16    .81   1.71   2.60   2.39
              1.69   1.06    .65    .41    .19    .11    .12    .07    .11    .05    .06    .04    .02    .00    .02
               .01    .00    .00    .00    .00    .00    .00    .00    .00    .00    .00    .00    .00    .00    .00    .00

R=   1.0  Z=5.00E 02  Q=   3  L=  .06  DL=1.5  NT=  44.58  NS=120      .04    .06    .49   1.06   3.43   7.48   7.99
              6.77   5.09   3.82   2.82   1.78   1.44    .91    .39    .25    .23    .14    .09    .07    .05    .00
               .04    .03    .03    .04    .02    .01    .00    .00    .00    .00    .00    .00    .01    .00    .01    .00    .00

R=   1.9  Z=9.80E 02  Q=   6  L=  .11  DL=1.5  NT=  77.44  NS=115      .06    .15    .53   1.23   4.22  11.39  14.40
             12.83   9.67   7.18   4.89   3.30   2.27   1.52   1.13    .88    .38    .34    .26    .21    .14    .11
               .10    .06    .05    .06    .04    .02    .00    .00    .01    .01    .00    .01    .00    .00    .00    .00    .00

R=   2.9  Z=1.29E 03  Q=   8  L=  .17  DL=1.6  NT= 109.64  NS= 83      .12    .18    .85   1.46   4.29  11.82  15.07
             16.82  17.06  13.27   9.55   7.01   4.50   2.35   2.01   1.20    .75    .36    .28    .18    .17    .15
               .09    .03    .05    .00    .00    .01    .00    .00    .00    .00    .00    .00    .00    .00    .00    .01    .00

R=   4.4  Z=2.29E 03  Q=  13  L=  .24  DL=1.6  NT= 141.06  NS=125      .08    .20    .63   1.72   4.95  13.41  16.86
             20.68  19.79  16.52  13.68   9.48   6.45   4.54   3.48   2.09   1.31   1.01    .77    .43    .20    .20
               .14    .00    .12    .07    .08    .02    .02    .01    .04    .01    .00    .00    .00    .00    .00    .00    .00
               .00  .01  .00  .00  .00  .00  .00  .00  .00  .00  .00 .00 .00 .00 .00 .00 .00 .00 .00 .00 .00 .00

R=   7.2  Z=5.45E 03  Q=  28  L=  .37  DL=1.8  NT= 178.07  NS=163      .13    .36    .74   2.12   4.68  12.54  17.52
             21.36  23.15  21.29  19.27  14.04  11.75   8.00   6.54   3.94   3.20   1.91   1.59    .89    .75    .63
               .33    .22    .22    .20    .17    .10    .11    .08    .08    .05    .03    .03    .02    .01    .01    .00    .00
               .01  .00  .00  .01  .00  .00  .00  .00  .00  .00  .00 .00 .00 .00 .00 .00 .00 .00 .00 .00 .00 .01 .00

R=  11.7  Z=9.47E 03  Q=  49  L=  .57  DL=1.9  NT= 224.50  NS=145      .23    .53   1.19   3.10   4.91  13.30  16.01
             19.72  22.20  23.86  23.21  20.36  17.90  14.02  12.17   7.56   6.81   4.90   3.54   2.49   1.74   1.12
               .97    .65    .61    .27    .24    .28    .18    .14    .07    .04    .04    .04    .03    .01    .01    .01    .01
               .01  .00  .00  .01  .00  .00  .00  .00  .00  .00  .00 .00 .00 .00 .00 .00 .00 .00 .00 .00 .01 .00 .00

R=  16.8  Z=1.90E 04  Q=  96  L=  .86  DL=2.1  NT= 274.92  NS= 82      .30    .82   2.34   4.81   7.05  13.76  15.19
             19.50  22.54  23.61  24.28  23.90  22.48  18.35  17.18  12.24  10.99   8.50   6.50   4.79   4.08   2.73
              2.44   1.67   1.40   1.03    .55    .62    .37    .31    .31    .14    .14    .10    .14    .08    .08    .01    .01
               .03  .01  .01  .00  .00  .00  .00  .00  .00  .00  .00 .00 .00 .00 .00 .00 .00 .00 .00 .01 .00 .00 .00

R=  30.5  Z=3.71E 04  Q= 162  L= 1.35  DL=2.2  NT= 380.01  NS= 73      .61   1.37   3.49   7.52  10.34  19.86  21.76
             25.07  28.01  29.74  29.92  28.32  27.49  24.10  24.40  18.47  15.89  12.77   9.93   8.66   6.90   5.69
              4.12   2.92   3.06   1.91   1.75   1.42    .89    .60    .60    .75    .40    .29    .31    .13    .10    .14    .09
               .04  .04  .00  .01  .03  .03  .01  .00  .00  .00  .01 .00 .01 .01 .00 .00 .00 .00 .00 .00 .00 .00 .00

R=  49.4  Z=7.55E 04  Q= 341  L= 2.10  DL=2.4  NT= 538.09  NS= 64     1.29   3.58   9.76  16.14  21.14  34.33  34.87
             34.30  35.69  33.63  33.00  32.18  32.34  29.71  30.42  24.65  23.87  19.19  16.29  13.04  10.75   8.60
              6.87   5.78   4.83   4.06   3.32   2.69   2.06   2.10   1.82   1.32    .97    .70    .66    .38    .43    .28    .21
               .13  .12  .12  .13  .07  .08  .05  .03  .03  .02  .03 .00 .02 .02 .00 .00 .00 .00 .00 .00 .00 .00 .00
               .02 .00 .00 .00 .00 .00 .00 .00 .00 .00 .00 .00 .00

R=  77.9  Z=1.13E 05  Q= 546  L= 3.30  DL=2.5  NT= 883.44  NS= 59     3.36  10.87  30.86  29.31  53.70  66.88  66.46
             57.69  53.97  50.64  44.52  41.12  41.14  35.72  41.91  35.36  35.05  30.87  27.67  23.30  19.24  15.62
             13.33  10.65  5.19  6.47  5.96  4.57  4.27  2.84  2.56  1.93  1.65  1.06   .74    .61    .47    .42   .36
               .24  .14  .13  .18  .07  .02  .07  .02  .00  .00  .00 .00 .02 .00 .00 .00 .00 .00 .00 .00 .02 .00 .00

R= 114.0  Z=1.74E 05  Q= 807  L= 4.86  DL=2.4  NT=1460.75  NS= 15     7.60  17.09  61.40  62.81 115.77 131.66 125.97
            100.37  93.97  87.00  74.59  61.61  67.66  44.80  58.10  43.82  48.18  41.64  37.98  30.59  26.73  22.44
             18.15  14.21 13.43 10.83  8.51  5.98  5.35  4.85  4.08  3.52  2.67  1.34  1.55  1.13   .84    .56   .49
               .35  .35  .14  .14  .07  .14  .00  .00  .07  .00  .14 .00 .07 .00 .00 .00 .00 .00 .00 .00 .07 .00 .00
```

detonation. Correlation between the number of large drops encountered and premature firing was unexpectedly low.

A major handicap in the detailed analysis has been an obvious inconsistency in the timing on the raingage charts. In future experiments, better timing of raingages, drop camera, and firing times should be maintained.

Surprisingly, at least to one observer, the number of firings at low to moderate rates (around .6 inch/hour) was less than desired from a statistical viewpoint. Since the critical rainfall is somewhere in this area, more data in this region will improve the analysis of the causes of premature detonations.

APPENDIX A

1968 Date	Time	Round No.	Distance to Burst	Fuze Type	Avg. Rate	Liquid Water	Total No. Drops	Encountered Drops No. ≥ 3.0	No. ≥ 3.5	No. ≥ 4.0	No. ≥ 4.5
7/ 5	1312	25	I	M564	.36	.16	65.8	.38	.094	.022	.011
7/ 5	1314	26	I	M564	.36	.16	65.8	.38	.094	.022	.011
7/ 5	1316	27	I	M564	.38	.17	67.4	.54	.12	.030	.014
7/ 5	1318	28	I	M564	.38	.17	67.4	.54	.12	.030	.014
7/ 5	1319	29	I	M564	.38	.17	67.4	.54	.12	.030	.014
7/ 7	0950	30	I	M564	.02	.02	9.48	.016	.0044	.00080	.00047
7/ 8	0246	31	I	M564	.28	.12	52.1	.18	.047	.011	.0056
7/ 8	0248	32	I	M564	.28	.12	52.1	.18	.047	.011	.056
7/ 9	0357	33	I	M564	.08	.03	19.0	.032	.0088	.0016	.00094
7/10	1945	34	I	M564	.22	.07	32.2	.11	.027	.0056	.0029
7/11	0551	35	I	M564	.36	.16	61.2	.40	.098	.023	.011
7/11	0552	36	I	M564	.36	.16	61.2	.40	.098	.023	.011
7/11	0552.5	37	I	M564	.36	.16	61.2	.40	.098	.023	.011
7/11	0553	38	I	M564	.36	.16	61.2	.40	.098	.023	.011
7/11	0554	39	I	DELAY	.36	.16	61.2	.40	.098	.023	.011
7/11	0556	40	I	U	.35	.13	53.2	.37	.09	.02	.0093
7/11	0556.5	41	I	U	.35	.13	53.2	.37	.09	.02	.0093
7/11	0557	42	I	U	.35	.13	53.2	.37	.09	.02	.0093
7/11	0558	43	I	U	.35	.13	53.2	.37	.09	.02	.0093
7/11	0558.5	44	I	U	.35	.13	53.2	.37	.09	.02	.0093
7/11	0559	45	I	U	.35	.13	53.2	.37	.09	.02	.0093
7/11	0559.5	46	I	M564	.35	.13	53.5	.37	.092	.020	.0093
7/11	0600	47	I	M564	.40	.17	61.2	.69	.16	.038	.016
7/11	0600.5	48	I	M564	.40	.17	61.2	.69	.16	.038	.016
7/11	0601	49	I	M564	.40	.17	61.2	.69	.16	.038	.016
7/11	0601.5	50	I	U	.40	.17	61.2	.69	.16	.038	.016
7/11	0602	51	I	U	.40	.17	61.2	.69	.16	.038	.016
7/11	0602.5	52	I	U	.40	.17	61.2	.69	.16	.038	.016
7/11	0603	53	I	U	.40	.17	61.2	.69	.16	.038	.016
7/11	0603.5	54	I	U	.40	.17	61.2	.69	.16	.038	.016
7/11	0604	55	I	M564	.40	.17	61.2	.69	.16	.038	.016
7/11	0605	56	I	M564	.25	.11	45.4	.32	.064	.014	.0068
7/11	0606	57	I	M564	.25	.11	45.4	.32	.064	.014	.0068
7/11	0606.5	58	I	M564	.25	.11	45.4	.32	.064	.014	.0068
7/11	0607	59	I	M564	.25	.11	45.4	.32	.064	.014	.0068
7/11	0607.5	60	I	STU	.25	.11	45.4	.32	.064	.014	.0068
7/11	0608	61	I	STU	.25	.11	45.4	.32	.064	.014	.0068
7/11	0609	62	I	STU	.25	.11	45.4	.32	.064	.014	.0068
7/11	0609.5	63	I	STU	.25	.11	45.4	.32	.064	.014	.0068
7/11	0610	64	I	STU	.11	.04	22.2	.058	.015	.0033	.0018
7/11	0611	65	I	DELAY	.11	.04	22.2	.058	.015	.0033	.0018

1968 Date	Time	Round No.	Distance to Burst	Fuze Type	Avg. Rate	Liquid Water	Total No. Drops	Encountered Drops No. ≥ 3.0	No. ≥ 3.5	No. ≥ 4.0	No. ≥ 4.5
7/11	1217	68									
7/11	1833	69									
7/11	1835	70									
7/11	1841	71									
7/11	1847	72									
7/11	1852	73									
7/11	1855	74									
7/12	1215	75									
7/14	0220	76	I	M564	.82	.31	99.3	19.9	5.2	1.2	.45
7/14	0221	77	E.B.								
7/14	0222	78	1130	M564	.82	.296	86.9	2.1	.55	.13	.046
.7/14	0223	79	60	M564	.82	.0173	5.8	.067	.016	.0037	.0016
7/14	0224	80	544	M564	.82	.0974	33.2	.39	.093	.021	.0095
7/14	0224.5	81	I	M564	.82	.31	99.3	19.9	5.2	1.2	.45
7/14	0225	82	I	M564	.07	.03	20.8	.025	.0071	.00080	.00047
7/14	0226	83	I	M564	.07	.03	20.8	.025	.0071	.00080	.00047
7/14	0227	84	I	M564	.07	.03	20.8	.025	.0071	.00080	.00047
7/14	0228	85	I	M564	.07	.03	20.8	.025	.0071	.00080	.00047
7/14	0229	86	I	STU	.07	.03	20.8	.025	.0071	.00080	.00047
7/14	0229.5	87	I	STU	.07	.03	20.8	.025	.0071	.00080	.00047
7/14	0230	88	I	STU	.05	.02	13.2	.019	.0053	.00080	.00047
7/14	0232	89	I	STU	.05	.02	13.2	.019	.0053	.00080	.00047
7/14	0233	90	I	STU	.05	.02	13.2	.019	.0053	.00080	.00047
7/14	0250	91	I	M564	1.36	.50	126.8	4.5	1.5	.34	.11
7/14	0251	92	I	M564	1.36	.50	126.8	4.5	1.5	.34	.11
7/14	0251.5	93	415	M564	1.36	.160	43.1	1.6	.53	.21	.04
7/14	0254	94	I	M564	1.36	.50	126.8	4.5	1.5	.34	.11
7/14	0255	95	390	M564	.74	.0699	19.7	.52	.13	.03	0
7/14	0257	96	I	U	.74	.28	84.2	1.7	.39	.090	.036
7/14	0258	97	I	U	.74	.28	84.2	1.7	.39	.090	.036
7/14	0259	98	I	U	.74	.28	84.2	1.7	.39	.090	.036
7/14	0300	99	I	U	.04	.02	11.3	.0095	.0027	0	0
7/14	0301	100	I	U	.04	.02	11.3	.0095	.0027	0	0
7/14	0302	101	I	DELAY	.04	.02	11.3	.0095	.0027	0	0
7/14	0314	102	I	STU	.83	.28	85.4	2.1	.61	.14	.049
7/14	0315	103	I	STU	.12	.05	26.5	.038	.011	.0016	.00094
7/14	0317	104	I	STU	.12	.05	26.5	.038	.011	.0016	.00094
7/14	0318	105	I	STU	.12	.05	26.5	.038	.011	.0016	.00094
7/14	0320	106	I	STU	.01	.006	3.78	.0032	.00091	0	0
7/14	1713	107									
7/14	1714	108									
7/14	1721	109									
7/14	1722	110									
7/15	1946	129	I	M564	.08	.02	18.9	.016	.0045	0	0
7/15	1947	130	I	STU	.08	.02	18.9	.016	.0045	0	0
7/15	1949	131	I	M564	.08	.02	18.9	.016	.0045	0	0

1968 Date	Time	Round No.	Distance to Burst	Fuze Type	Avg. Rate	Liquid Water	Total No. Drops	Encountered Drops No. ≥ 3.0	No. ≥ 3.5	No. ≥ 4.0	No. ≥ 4.5
7/15	1951	132	I	STU	.07	.03	17.0	.022	.0062	.00080	.00047
7/15	1956	133	I	M564	.29	.11	52.6	.17	.044	.0098	.0052
7/15	1957	134	I	STU	.29	.11	52.6	.17	.044	.0098	.0052
7/15	1958	135	I	M564	.29	.11	52.6	.17	.044	.0098	.0052
7/15	1959	136	I	M564	.29	.11	52.6	.17	.044	.0098	.0052
7/15	2000	137	I	STU	.22	.11	54.0	.15	.04	.009	.005
7/15	2001	138	I	M564	.22	.11	54.0	.15	.04	.009	.005
7/15	2002	139	I	M564	.22	.11	54.0	.15	.04	.009	.005
7/15	2003	140	I	STU	.22	.11	54.0	.15	.04	.009	.005
7/15	2004	141	I	M564	.22	.11	54.0	.15	.04	.009	.005
7/15	2005	142	I	STU	.24	.13	56.0	.24	.06	.013	.006
7/15	2007	143	I	M564	.24	.13	56.0 .	.24	.06	.013	.006
7/15	2008	144	I	M564	.24	.13	56.0	.24	.06	.013	.006
7/15	2009	145	I	STU	.24	.13	56.0	.24	.06	.013	.006
7/15	2015	146	I	M564	3.07	1.08	300.5	12.5	4.8	1.1	.33
7/15	2016	147	DUD	M564	3.07	1.08	300.5	12.5	4.8	1.1	.33
7/15	2017	148	860	M564	3.07	.544	144.9	5.9	2.1	.51	.12
7/15	2018	149	60	M564	3.07	.0665	18.2	.73	.27	.05	.02
7/15	2019	150	270	M564	3.07	.210	57.1	2.0	.66	.16	.05
7/15	2020	151	630	M564	4.27	.619	187.3	8.2	3.6	.86	.23
7/15	2021	152	I	STU	4.27	1.45	441.5	19.6	8.8	2.1	.56
7/15	2022	153	1410	M564	4.27	1.16	348.5	15.4	6.7	1.6	.44
7/15	2023	154	I	STU	4.27	1.45	441.5	19.6	8.8	2.1	.56
7/15	2023.5	155	360	M564	4.27	.440	126.4	5.48	2.28	.39	.15
7/15	2024	156	I	STU	4.27	1.45	441.5	19.6	8.8	2.1	.56
7/15	2025	157	1600	M564	4.75	1.47	457.1	20.7	9.8	2.3	.61
7/15	2026	158	I	STU	4.75	1.51	333.3	21.1	9.8	2.4	.62
7/15	2027	159	370	M564	4.75	.650	201.1	9.8	4.9	1.1	.29
7/15	2028	160	I	STU	4.75	1.51	333.3	21.1	9.8	2.4	.62
7/15	2029	161	1300	M564	4.75	1.25	404.0	18.0	8.6	2.1	.51
7/15	2030	162	520	M564	3.91	.618	202.3	9.1	4.4	1.1	2.7
7/15	2031	163	610	M564	3.91	.725	237.4	10.6	5.1	1.3	.31
7/15	20 32	164	280	DELAY	3.91	.442	142.1	5.8	2.7	.67	.17
7/15	2034	165	290	DELAY	3.91	.458	147.1	6.0	2.8	.69	.17
7/15	2035	166	I	STU	2.79	1.01	287.0	11.8	4.6	1.2	.31
7/15	2037	167	I	STU	2.79	1.01	287.0	11.8	4.6	1.2	.31
7/15	2038	168	I	STU	2.79	1.01	287.0	11.8	4.6	1.2	.31
7/15	2040	169	I	STU	2.12	.77	203.8	17.8	7.5	.58	.18
7/15	2041	170	I	STU	2.12	.77	203.8	17.8	7.5	.58	.18
7/15	2042	171	1593	DELAY	2.12	.783	208.0	7.7	2.5	.60	.19
7/15	2043	172	I	STU	2.12	.77	203.8	17.8	7.5	.58	.18
7/15	2044	173	630	DELAY	2.12	.383	101.1	3.7	1.2	.29	.089
7/15	2045	174	I	STU	2.27	.77	205.4	7.4	2.4	.56	.18
7/15	2046	175	490	DELAY	2.27	.334	90.1	3.4	1.2	.28	.085
7/15	2046.5	176	DUD	STU	2.27	.77	205.4	7.4	2.4	.56	.18
7/15	2047	177	110	DELAY	2.27	.127	35.2	1.1	.39	.093	.027

1968 Date	Time	Round No.	Distance to Burst	Fuze Type	Avg. Rate	Liquid Water	Total No. Drops	Encountered Drops No. ≥ 3.0	No. ≥ 3.5	No. ≥ 4.0	No. ≥ 4.5
7/15	2048	178	I	STU	2.27	.77	205.4	7.4	2.4	.56	.18
7/15	2049	179	670	DELAY	2.27	.415	111.8	4.3	1.5	.35	.11
7/15	2050	180	I	STU	1.30	.47	135.1	10.6	4.0	.30	.094
7/15	2051	181	1510	DELAY	1.30	.469	132.6	3.9	1.2	.29	.092
7/15	2052	182	I	STU	1.30	.47	135.1	10.6	4.0	.30	.094
7/15	2052.5	183	520	DELAY	1.30	.284	77.2	2.7	.87	.22	.064
7/15	2053	184	I	STU	1.30	.47	135.1	10.6	4.0	.30	.094
7/15	2054	185	I	DELAY							
7/15	2055	186	I	STU	.22	.09	40.0	.24	.058	.012	.0056
7/15	2214	188	I	DELAY	.31	.12	54.3	.23	.057	.013	.0063
7/15	2215	189	I	STU	.21	.09	41.4	.14	.036	.0078	.0041
7/16	0100	190	I	M564	.07	.03	17.0	.022	.0062	.00080	.00047
7/16	0101	191	I	STU	.07	.03	17.0	.022	.0062	.00080	.00047
7/16	0102	192	I	STU	.07	.03	17.0	.022	.0062	.00080	.00047
7/16	0103	193	I	STU	.07	.03	17.0	.022	.0062		
7/16	0104	194	I	STU	.07	.03	17.0	.022	.0062	.00080	.00047
7/16	0105	195	I	STU	.00						
7/16	0107	196	I	STU	.00						
7/16	0108	197	I	STU	.00						
7/16	0109.5	198	I	STU	.00						
7/16	0111.5	199	I	STU	.01	.005	3.8	.0032	.00091	0	0
7/16	0112.5	200	I	STU	.01	.005	3.8	.0032	.00091	0	0
7/16	1023	201	I	M564	.00						
7/16	1024	202	I	STU	.00						
7/16	1025	203	I	M564	.00						
7/16	1026	204	I	STU	.00						
7/16	1027	205	930	M564	.00						
7/16	1028	206	I	STU	.00						
7/16	1029	207	I	M564	.00						
7/16	1030.5	208	I	STU	.00						
7/16	1032	209	I	M564	.00						
7/16	1033	210	I	STU	.00						
7/17	1740	212	I	STU							
7/17	1743	213	I	STU							
7/17	1745	214	I	STU							
7/17	1750	215	I	STU							
7/19	0322	216	I	M564	.56	.19	59.2	1.2	.28	.064	.025
7/19	0324	217	I	STU	.56	.19	59.2	1.2	.28	.064	.025
7/19	0325	218	I	M564	.79	.32	93.9	2.2	.56	.13	.048
7/19	0327	219	I	STU	.79	.32	93.9	2.2	.56	.13	.048
7/19	0328	220	I	M564	.79	.32	93.9	2.2	.56	.13	.048
7/19	0329	221	I	STU	.79	.32	93.9	2.2	.56	.13	.048
7/19	0330	222	I	M564	.90	.34	103.0	2.2	.55	.13	.048
7/19	0331	223	I	STU	.90	.34	103.0	2.2	.55	.13	.048
7/19	0337	224	I	M564	.99	.32	97.6	1.9	.46	.11	.04
7/19	0338	225	I	STU	.99	.32	97.6	1.9	.46	.11	.04

1968 Date	Time	Round No.	Distance to Burst	Fuze Type	Avg. Rate	Liquid Water	Total No. Drops	Encountered Drops No. ≥ 3.0	No. ≥ 3.5	No. ≥ 4.0	No. ≥ 4.5
7/19	0339	226	I	STU	.99	.32	97.6	1.9	.46	.11	.04
7/19	0342	227	I	STU	.64	.20	70.6	.86	.19	.05	.02
7/19	0343	228	I	STU	.64	.20	70.6	.86	.19	.05	.02
7/19	0343.5	229	I	STU	.64	.20	70.6	.86	.19	.05	.02
7/19	0344	230	I	STU	.64	.20	70.6	.86	.19	.05	.02
7/19	0345	231	I	STU	.43	.14	56.0	.26	.10	.02	.01
7/19	0346	232	I	STU	.43	.14	56.0	.26	.10	.02	.01
7/19	0347	233	I	STU	.43	.14	56.0	.26	.10	.02	.01
7/19	0348	234	I	STU	.43	.14	56.0	.26	.10	.02	.01
7/19	0349	235	I	STU	.43	.14	56.0	.26	.10	.02	.01
7/19	0350	236	I	STU	.32	.10	43.5	.25	.06	.013	.006
7/19	0351	237	I	STU	.32	.10	43.5	.25	.06	.013	.006
7/19	0352.5	238	I	STU	.32	.10	43.5	.25	.06	.013	.006

Key

Distance to Burst - I denotes impact area. Distance to Early Burst is given in meters

Fuze Type - M564 - standard unmodified
U - urethane cap
STU - steel tipped urethane cap
DELAY - M564 with cartridge delay element

Avg. Rate - Average rainfall rate between the gun and point of detonation

Liquid Water - The liquid water content encountered by the sensitive portion of fuze between the gun and point of detonation

Encountered Drops - These numbers represent the expected number of drops of the indicated sizes encountered by the sensitive area of the fuze between the gun and the point of detonation

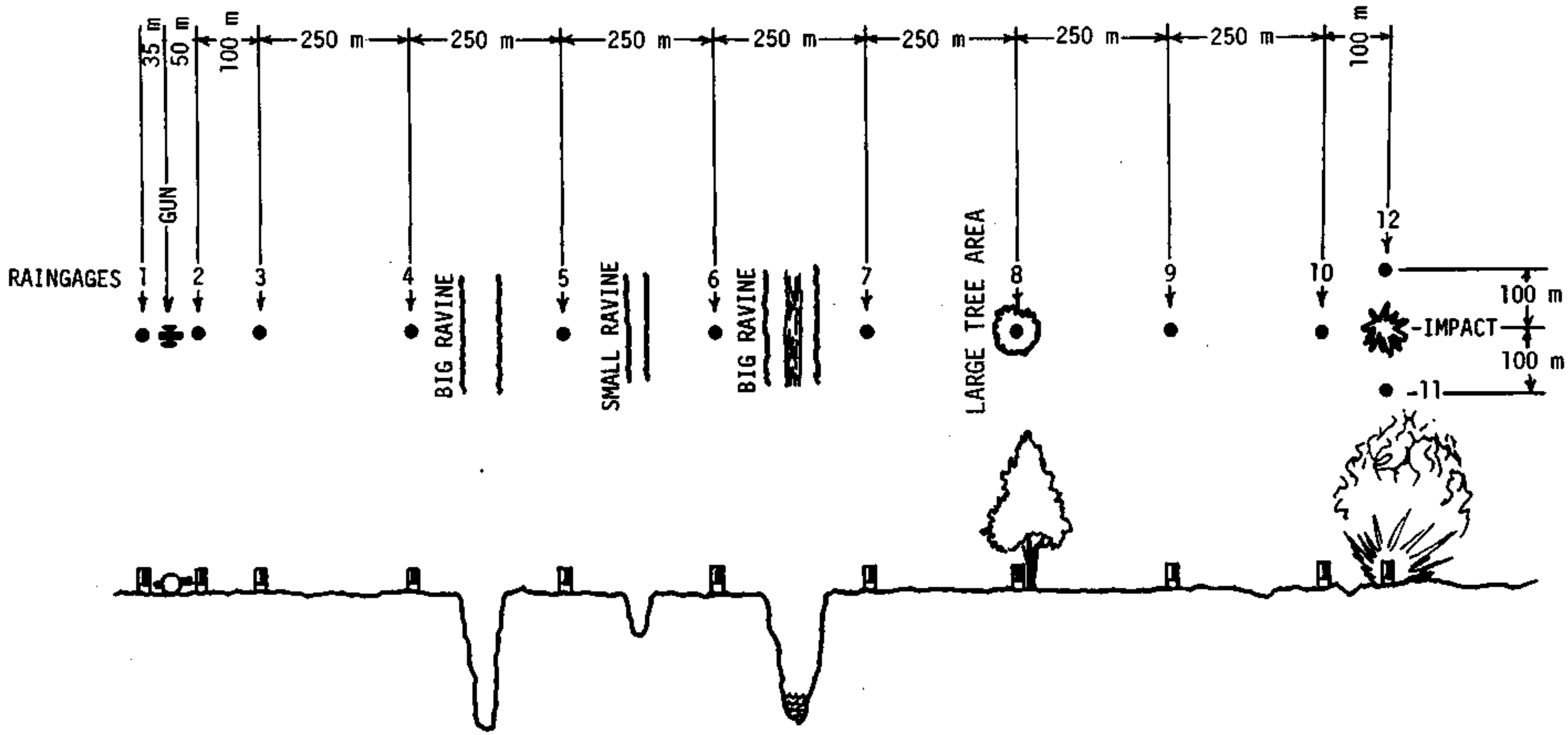

Figure 1. Location of raingages on the Piña Range

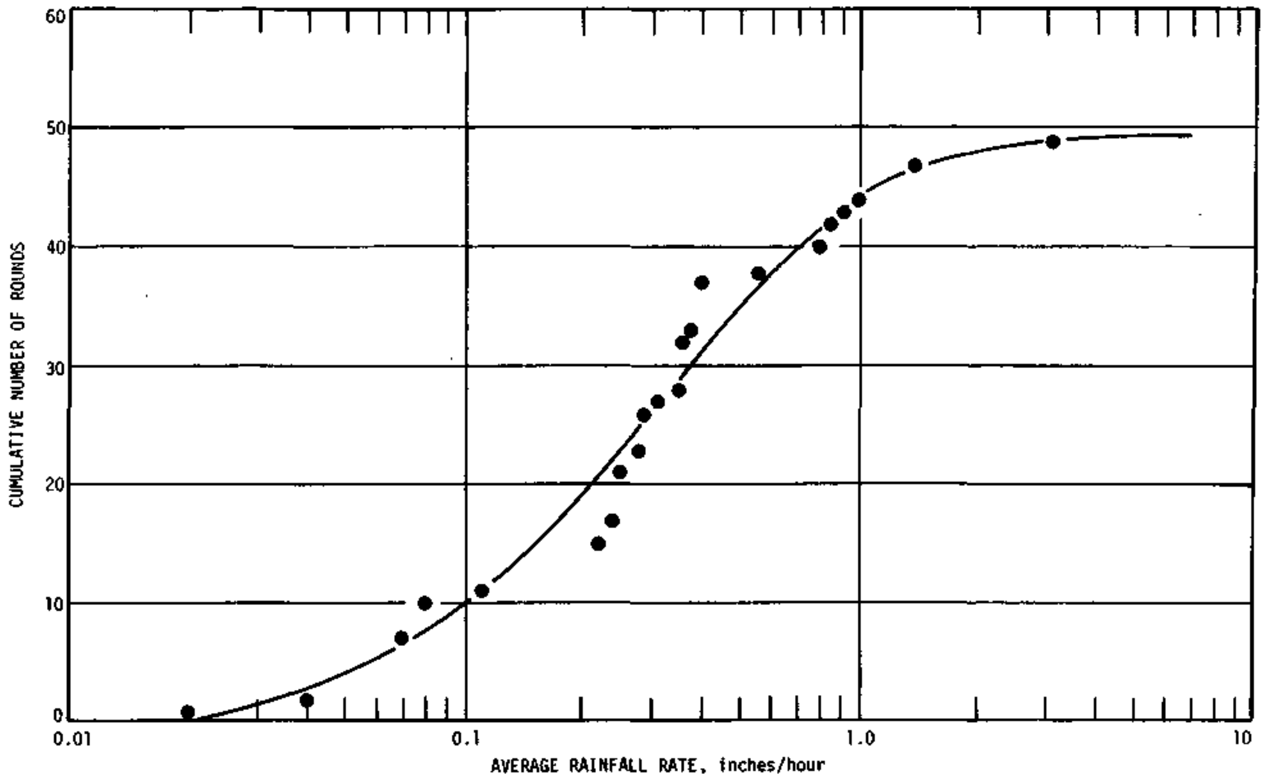

Figure 2. Frequency of rain rates when standard fuze penetrated to impact area

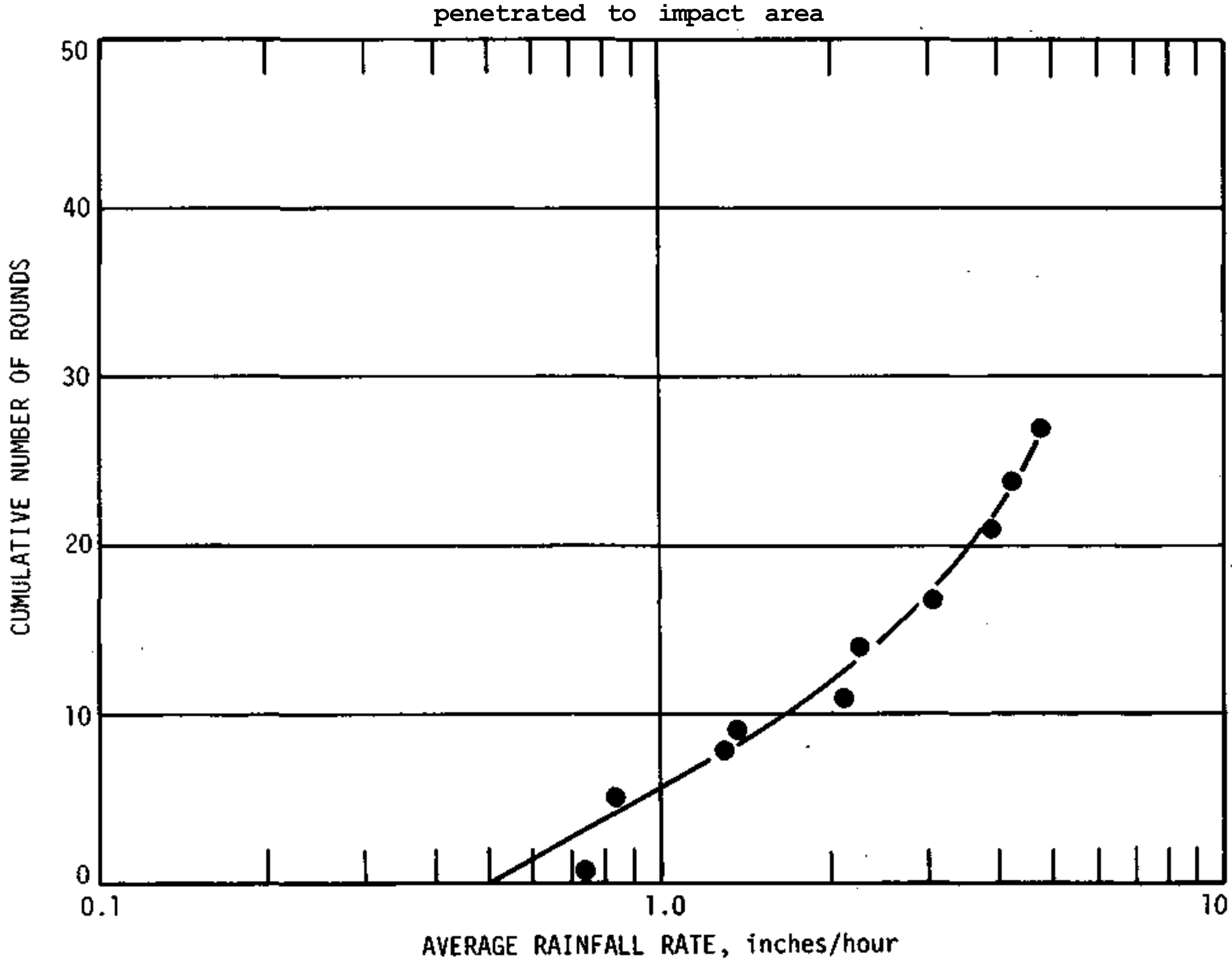

Figure 3. Frequency of rain rates when standard fuze fired prematurely

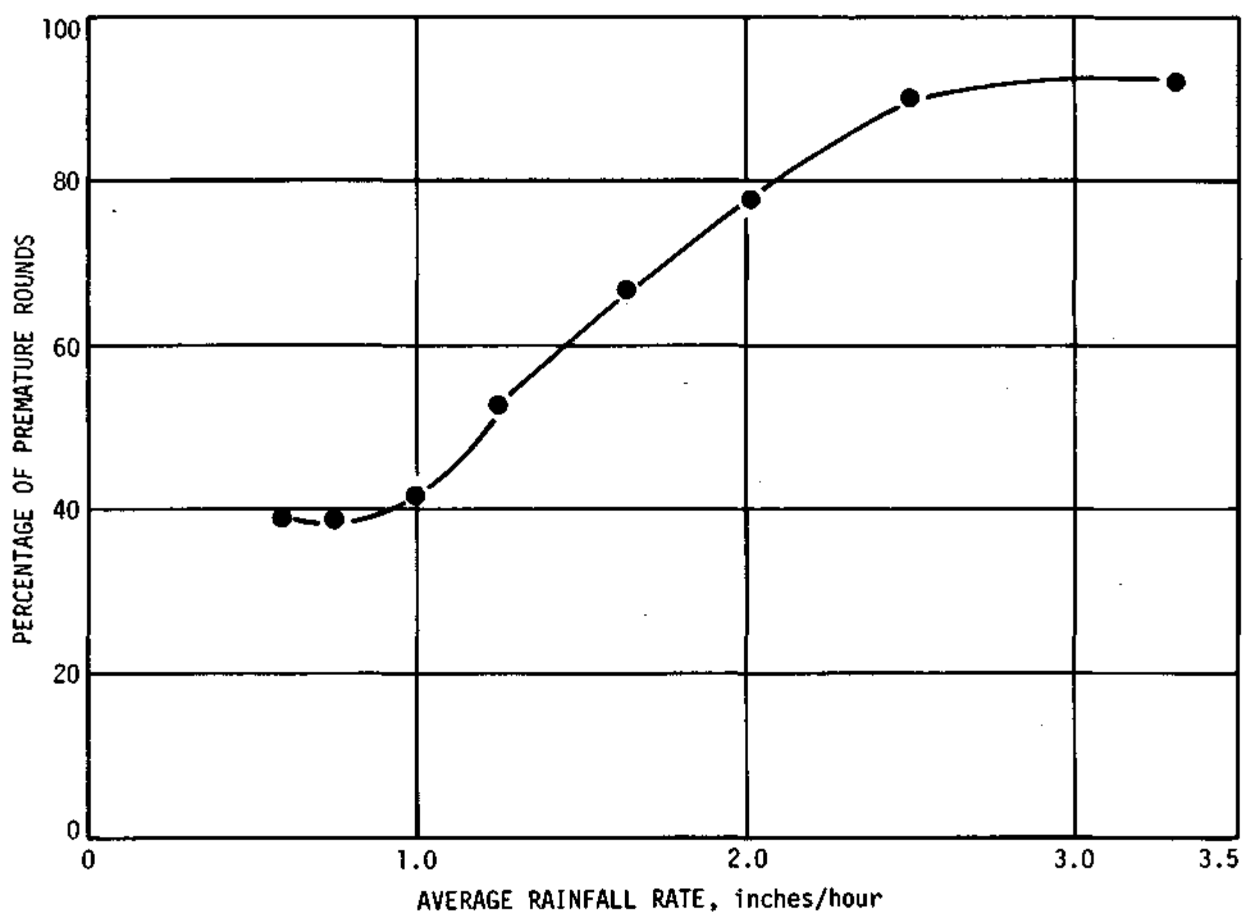

Figure 4. Average percentage of standard rounds which fired prematurely as a function of rainfall rate

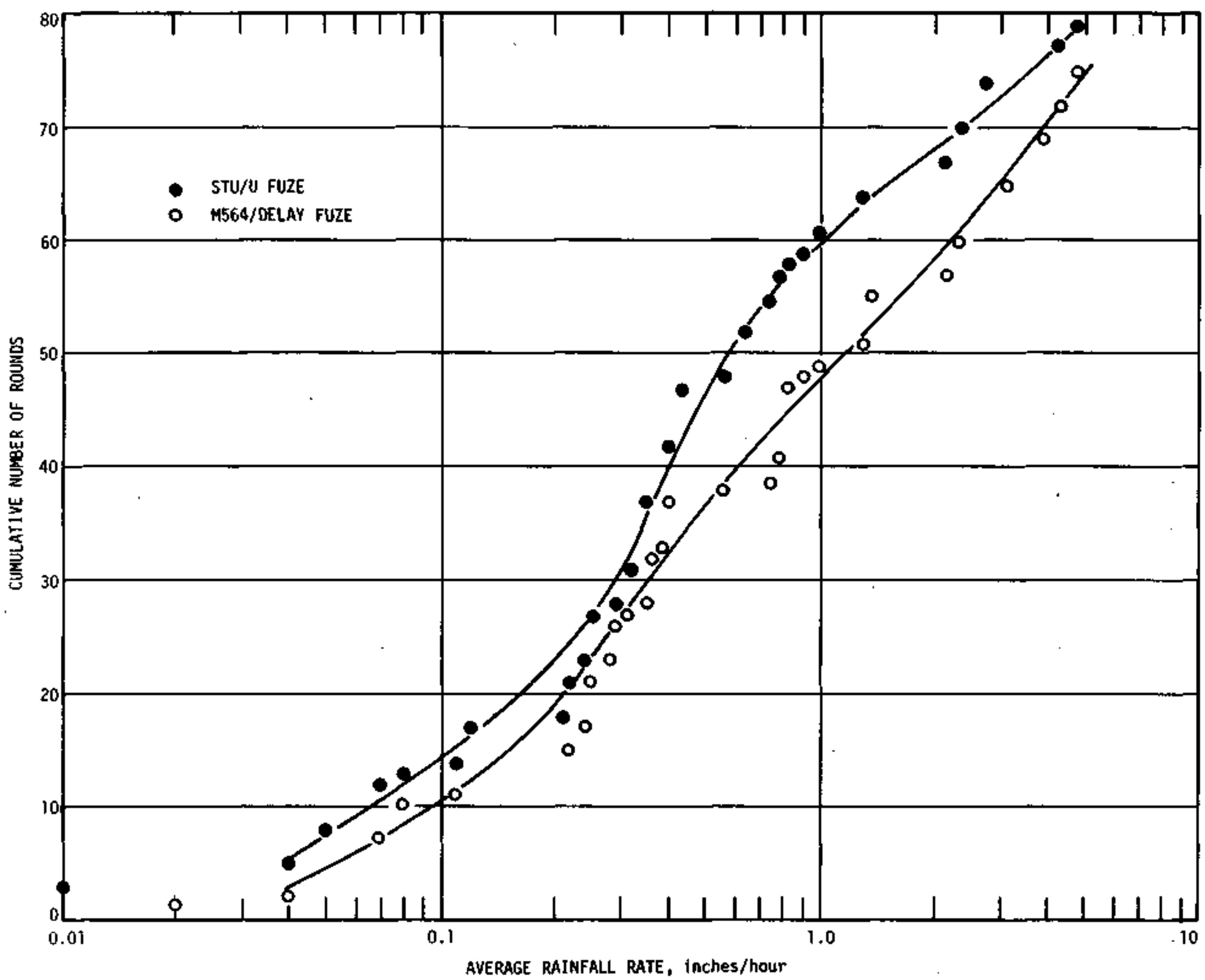

Figure 5. Cumulative frequency of rain rate for both types of fuze

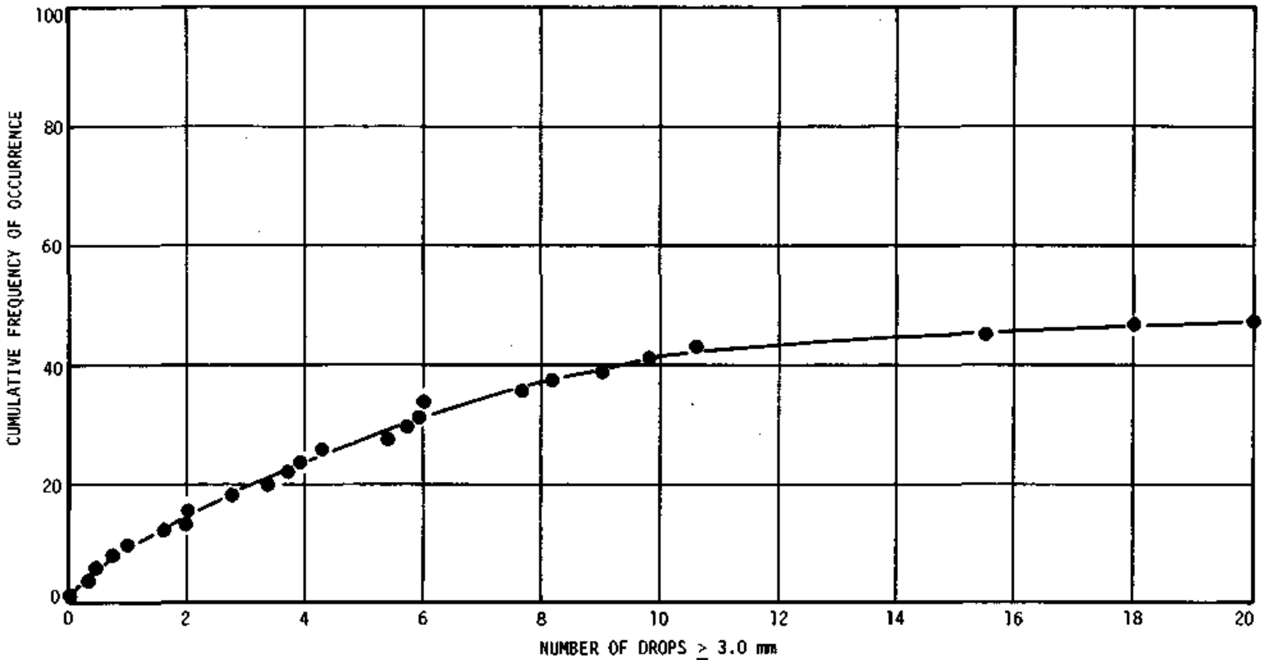

Figure 6. Cumulative frequency of rounds which fired prematurely as a function of expected number of drop collisions with drops greater than 3.0 mm diameter

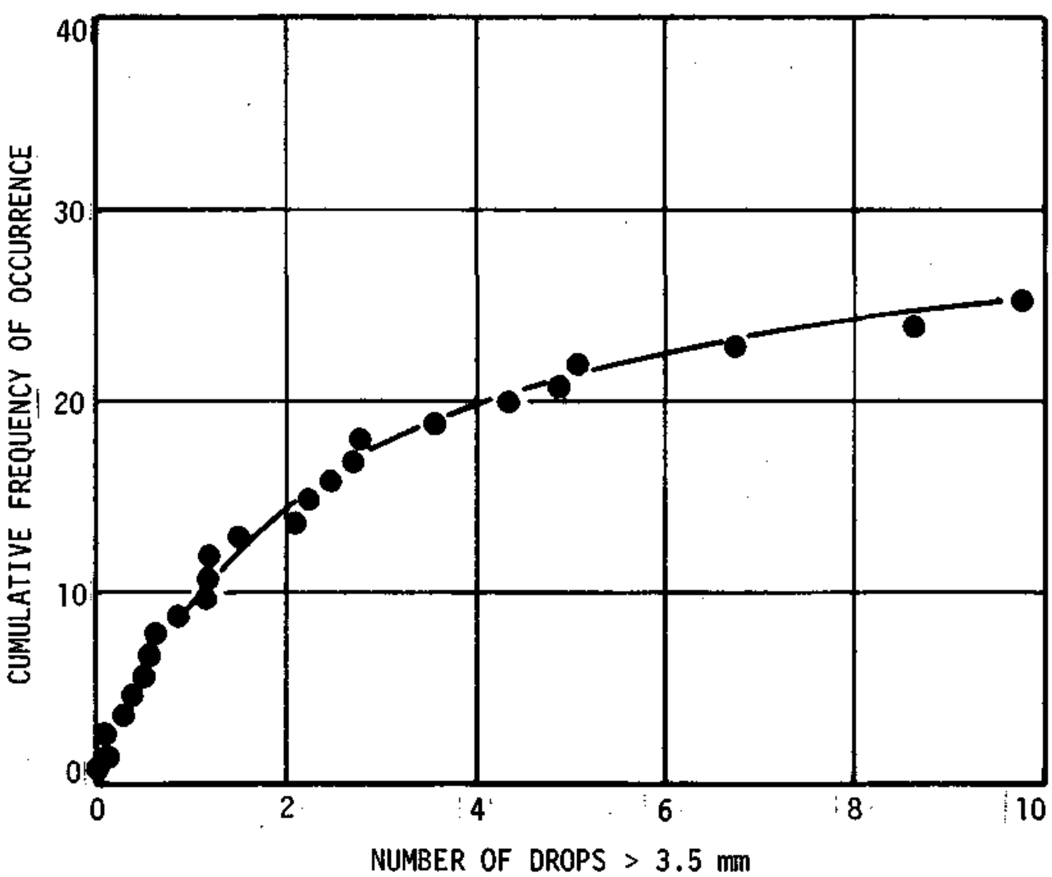

Figure 7. Cumulative frequency of rounds which fired prematurely as a function of expected number of drop collisions with drops greater than 3.5 mm diameter

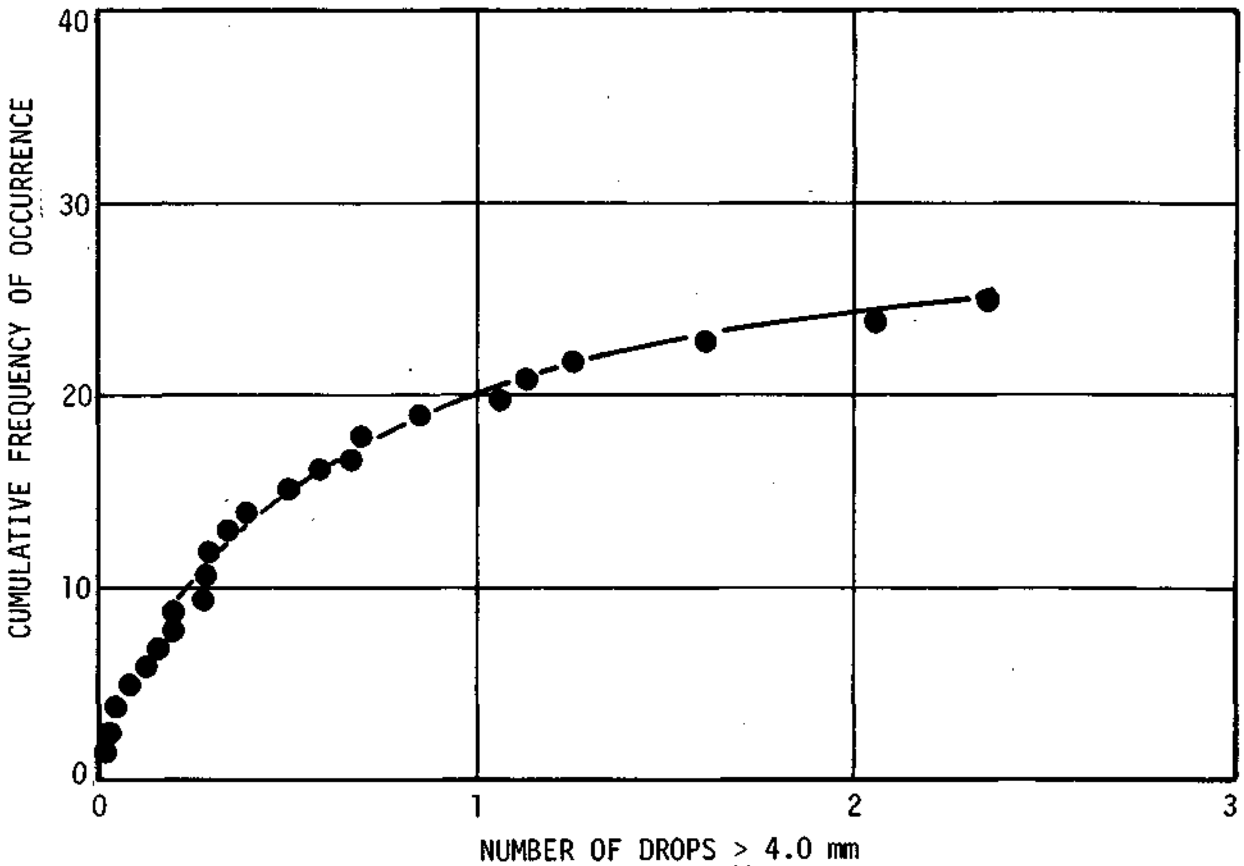

Figure 8. Cumulative frequency of rounds which fired prematurely as a function of expected number of drop collisions with drops greater than 4.0 mm diameter

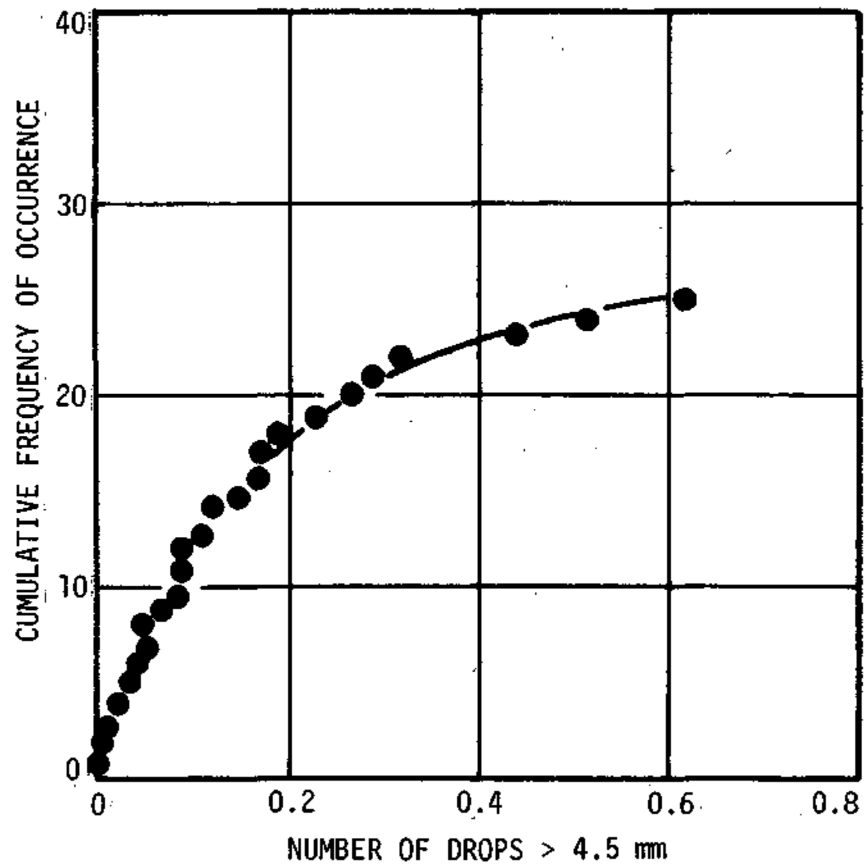

Figure 9. Cumulative frequency of rounds which fired prematurely as a function of expected number of drop collisions with drops greater than 4.5 mm diameter

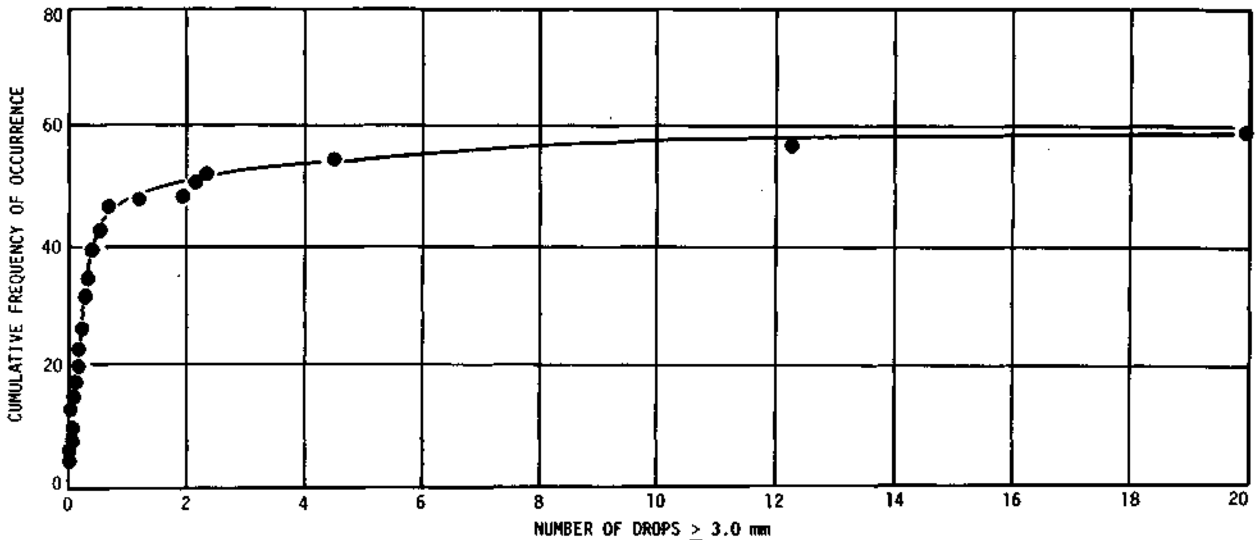

Figure 10. Cumulative frequency of rounds into impact area as a function of expected number of drop collisions with drops greater than 3.0 mm diameter

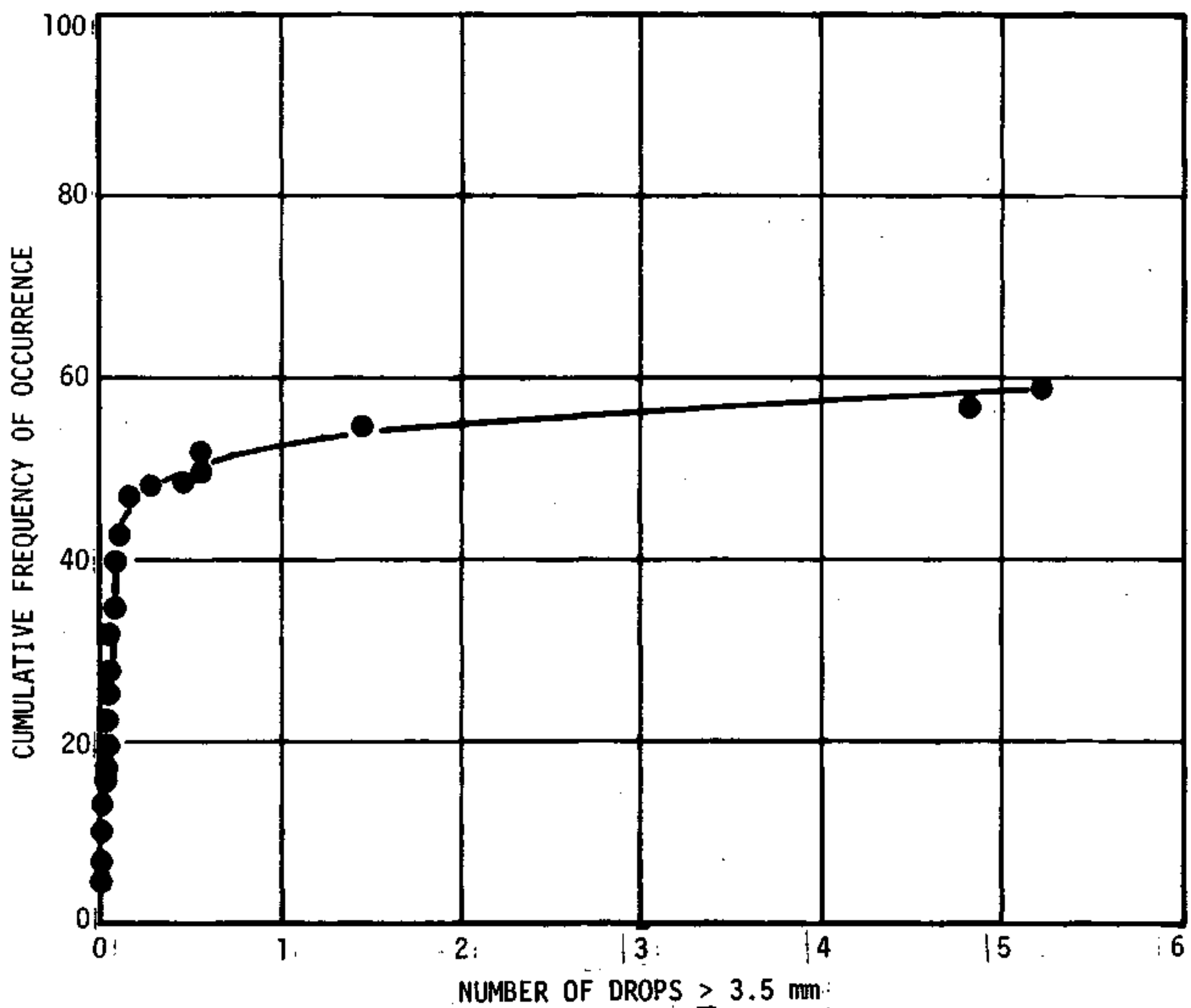

Figure 11. Cumulative frequency of rounds into impact area as a function of expected number of drop collisions with drops greater than 3.5 mm diameter

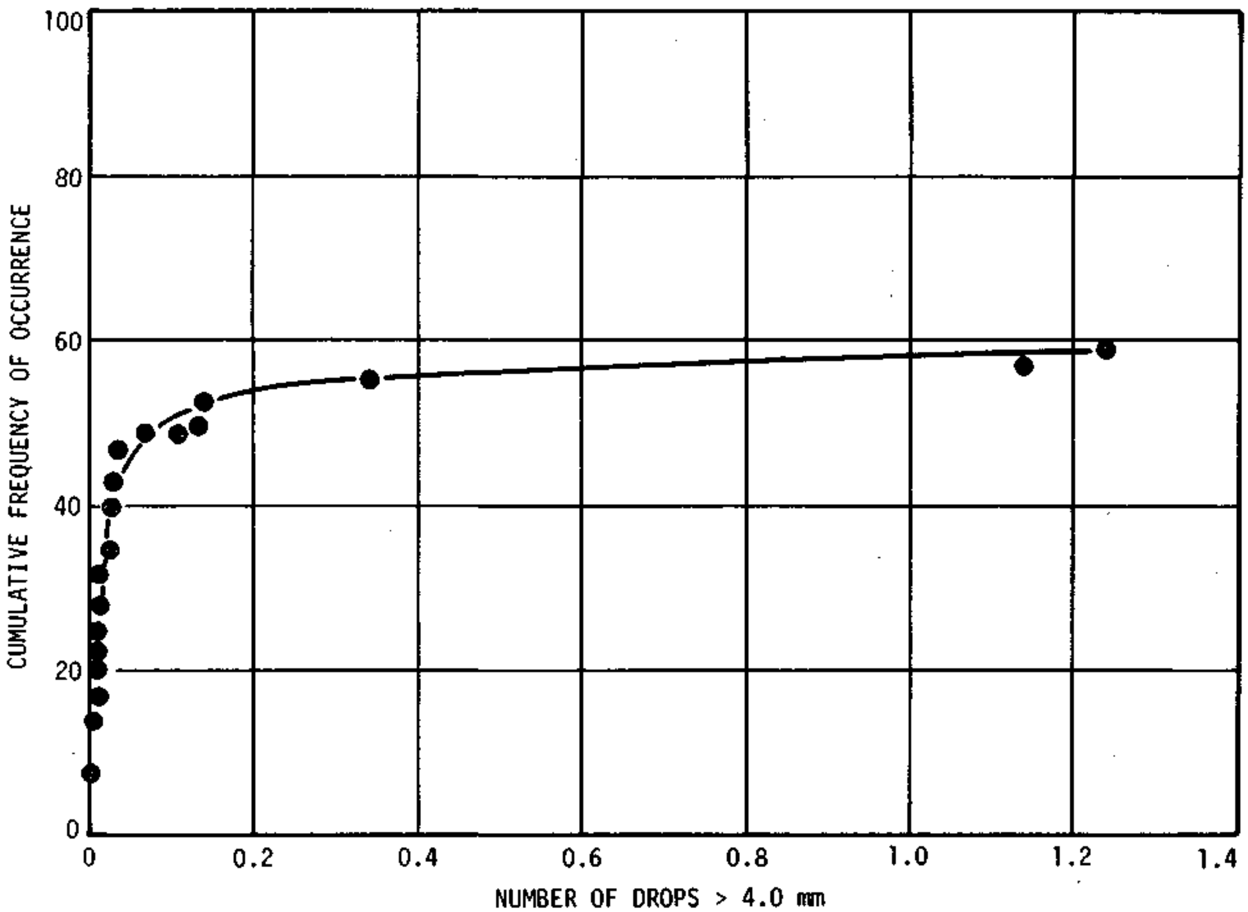

Figure 12. Cumulative frequency of rounds into impact area as a function of expected number of drop collisions with drops greater than 4.0 mm diameter

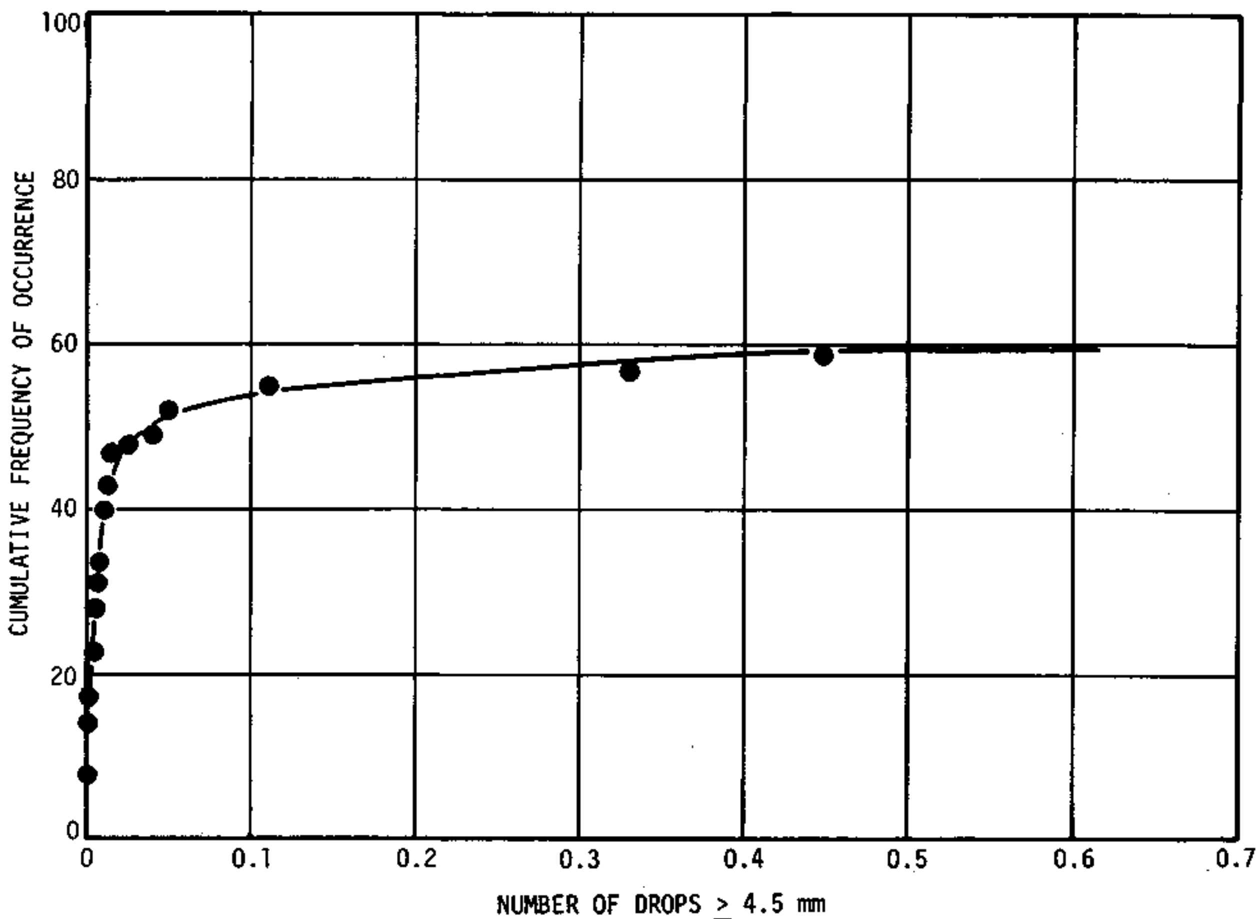

Figure 13. Cumulative frequency of rounds into impact area as a function of expected number of drop collisions with drops greater than 4.5 mm diameter

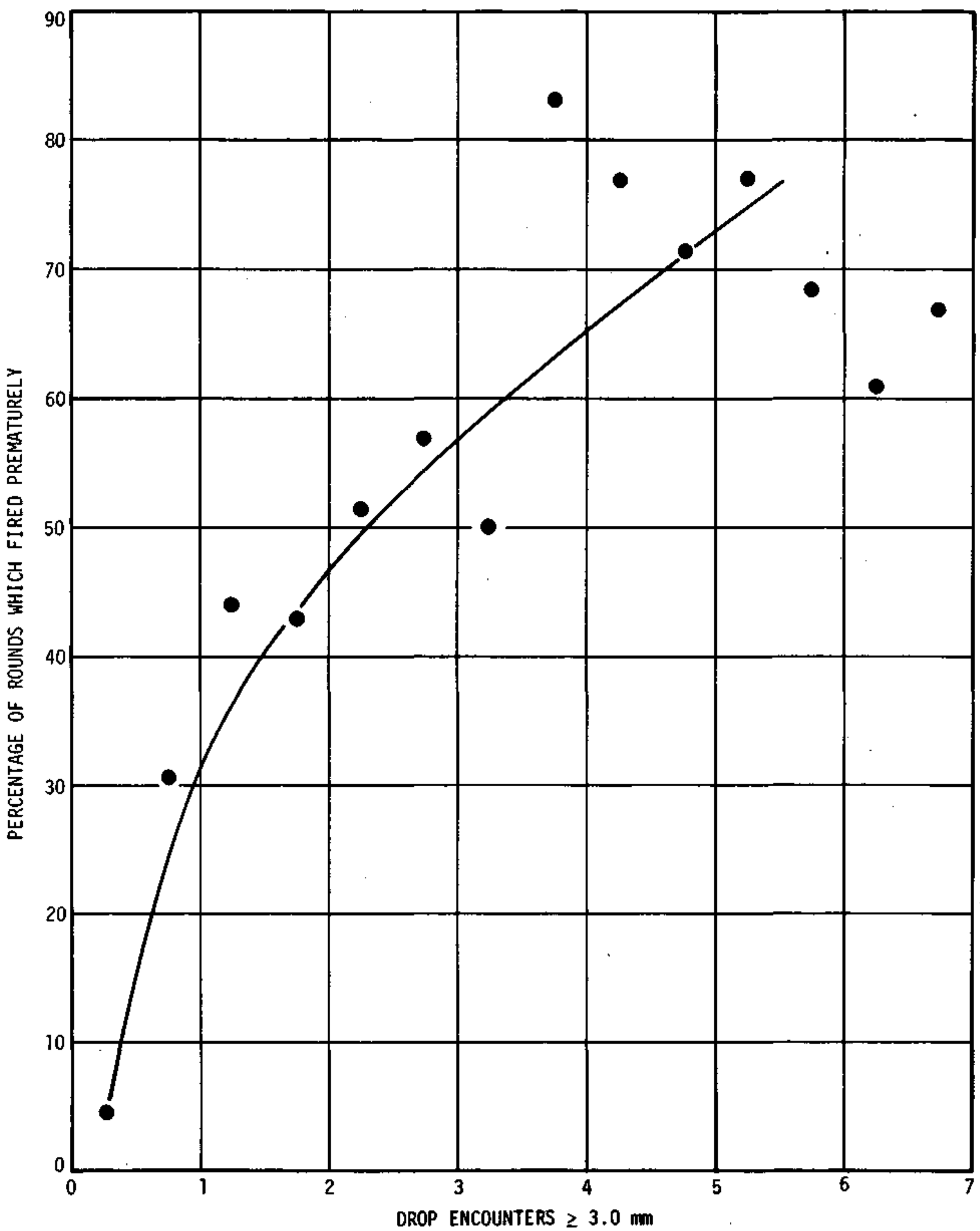

Figure 14. Probability of premature firing as a function of expected number of drop collisions with drops greater than 3.0 mm diameter

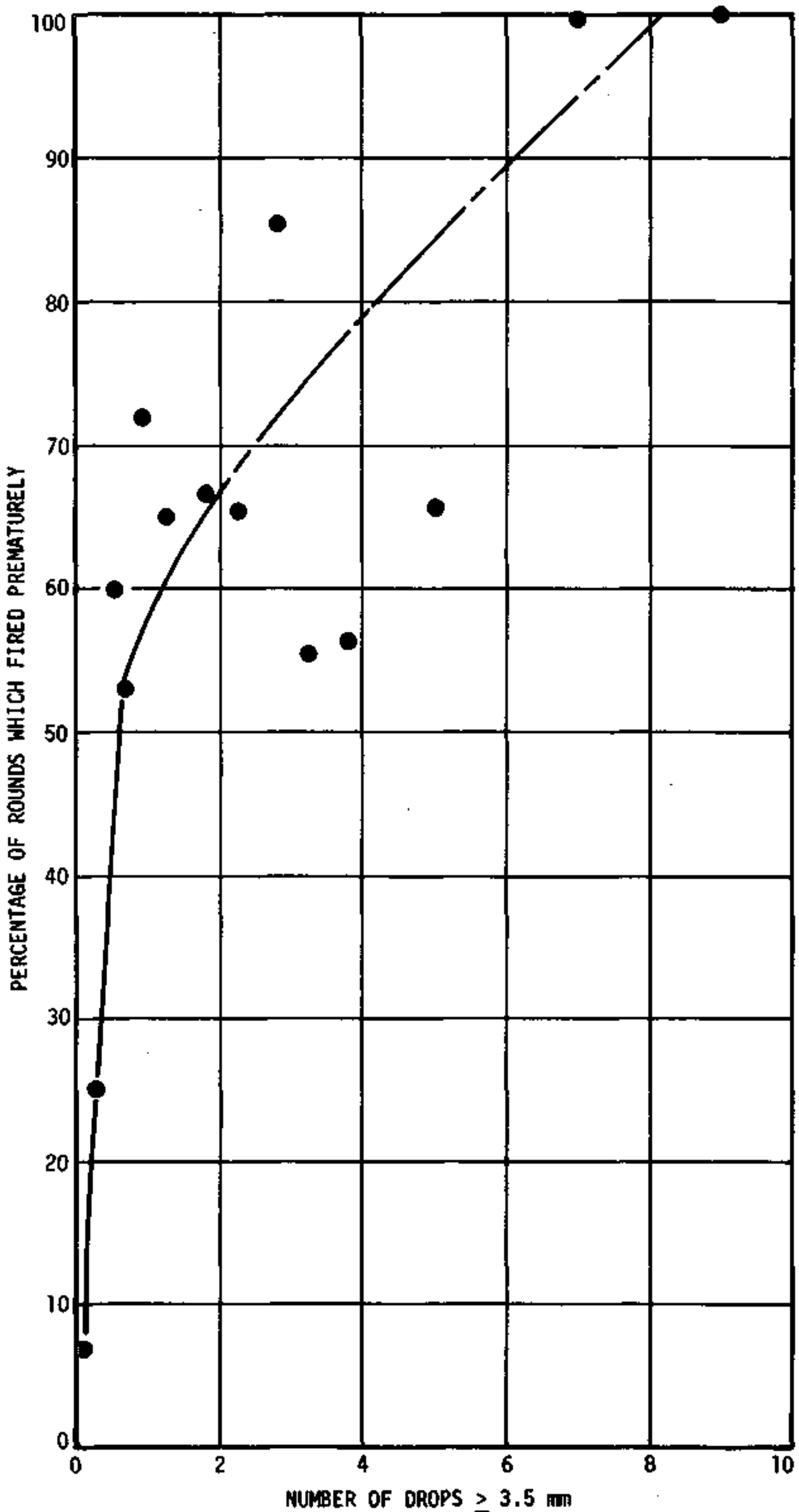

Figure 15. Probability of premature firing as a function of expected number of drop collisions with drops greater than 3.5 mm diameter

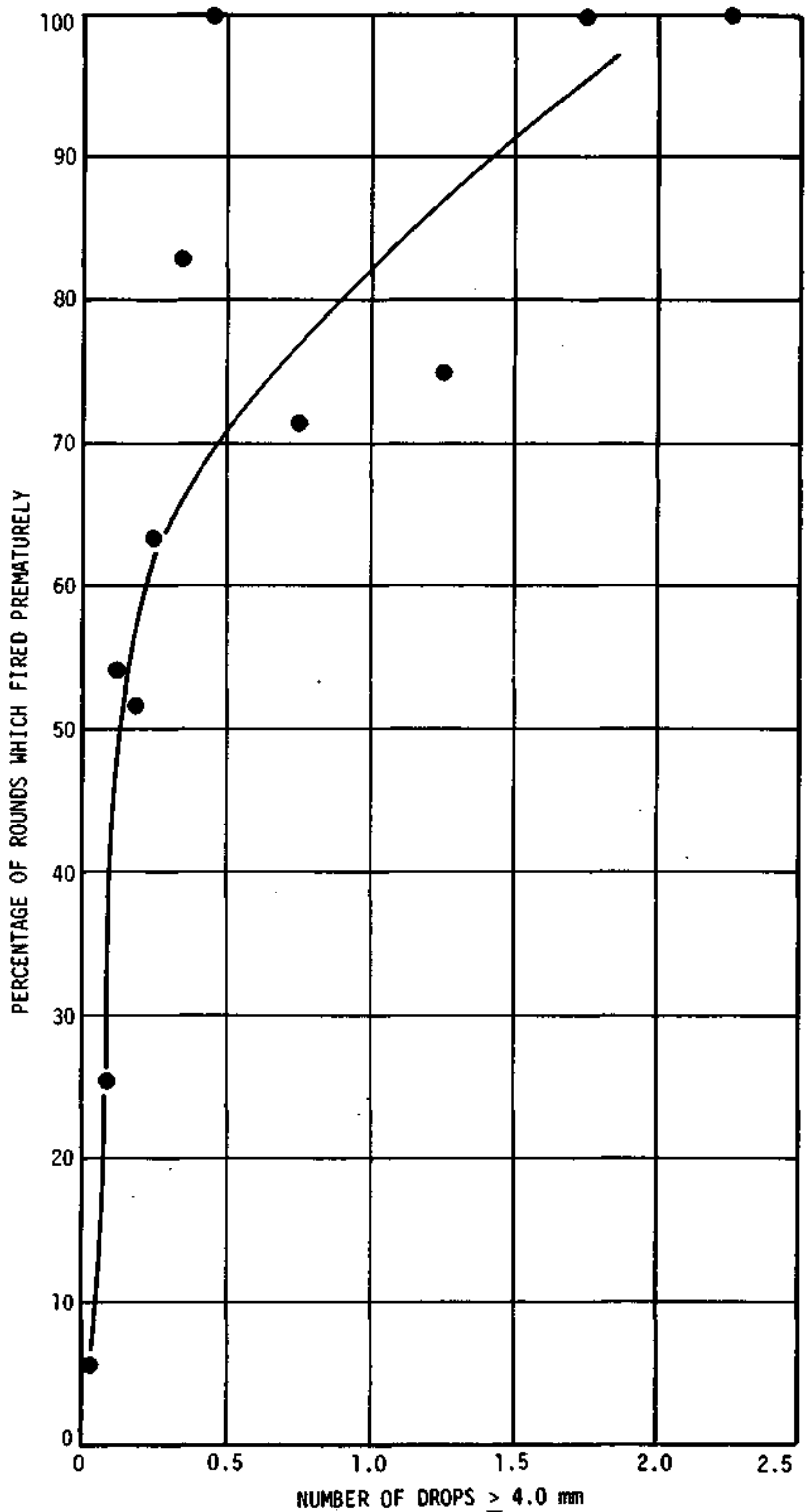

Figure 16. Probability of premature firing as a function of expected number of drop collisions with drops greater than 4.0 mm diameter

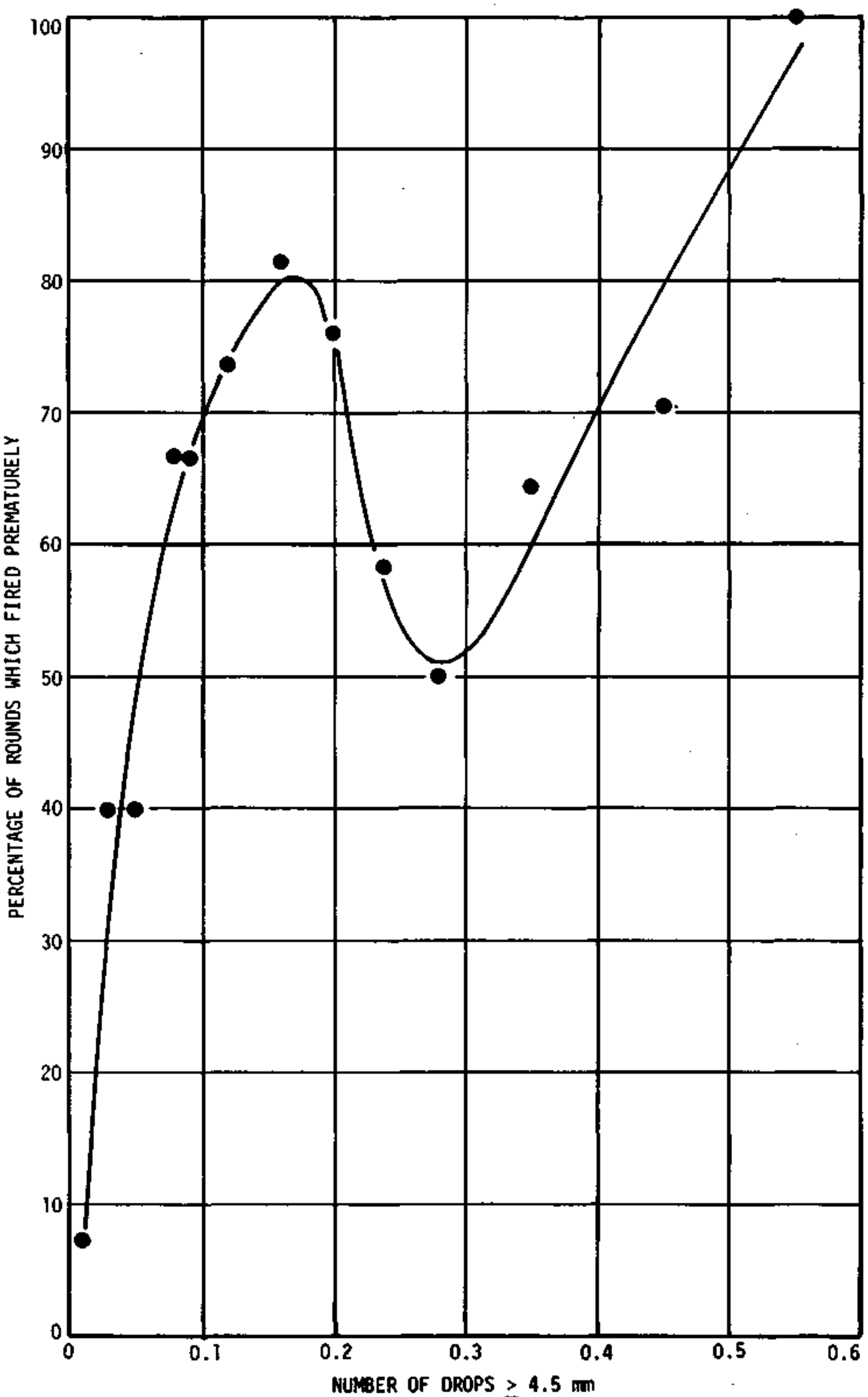

Figure 17. Probability of premature firing as a function of expected number of drop collisions with drops greater than 4.5 mm diameter

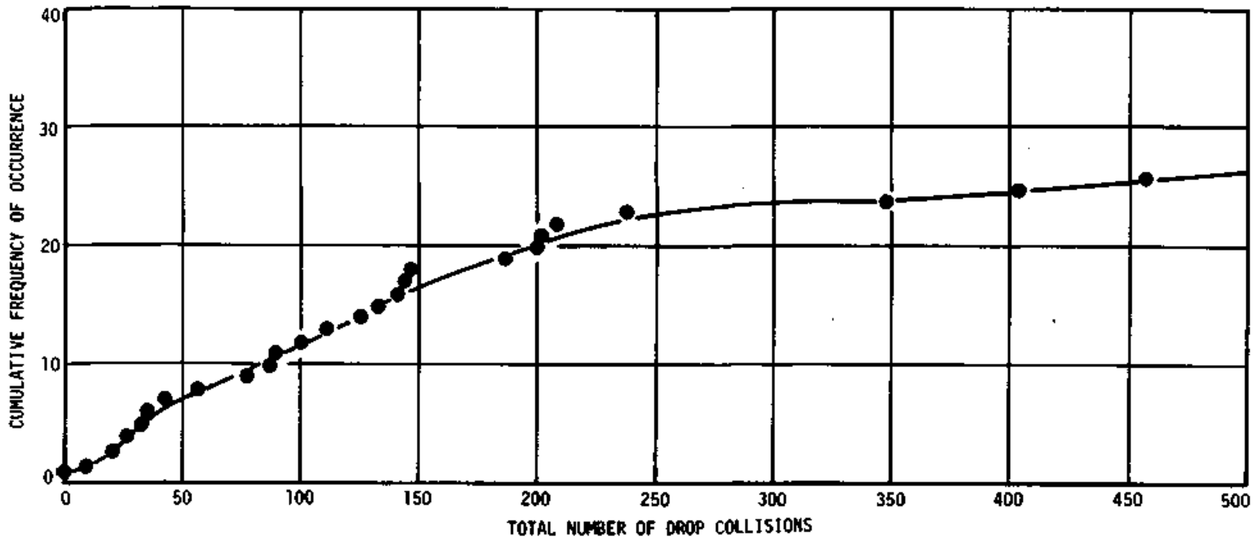

Figure 18. Cumulative frequency of rounds which fired prematurely as a function of expected number of drop collisions with all raindrops

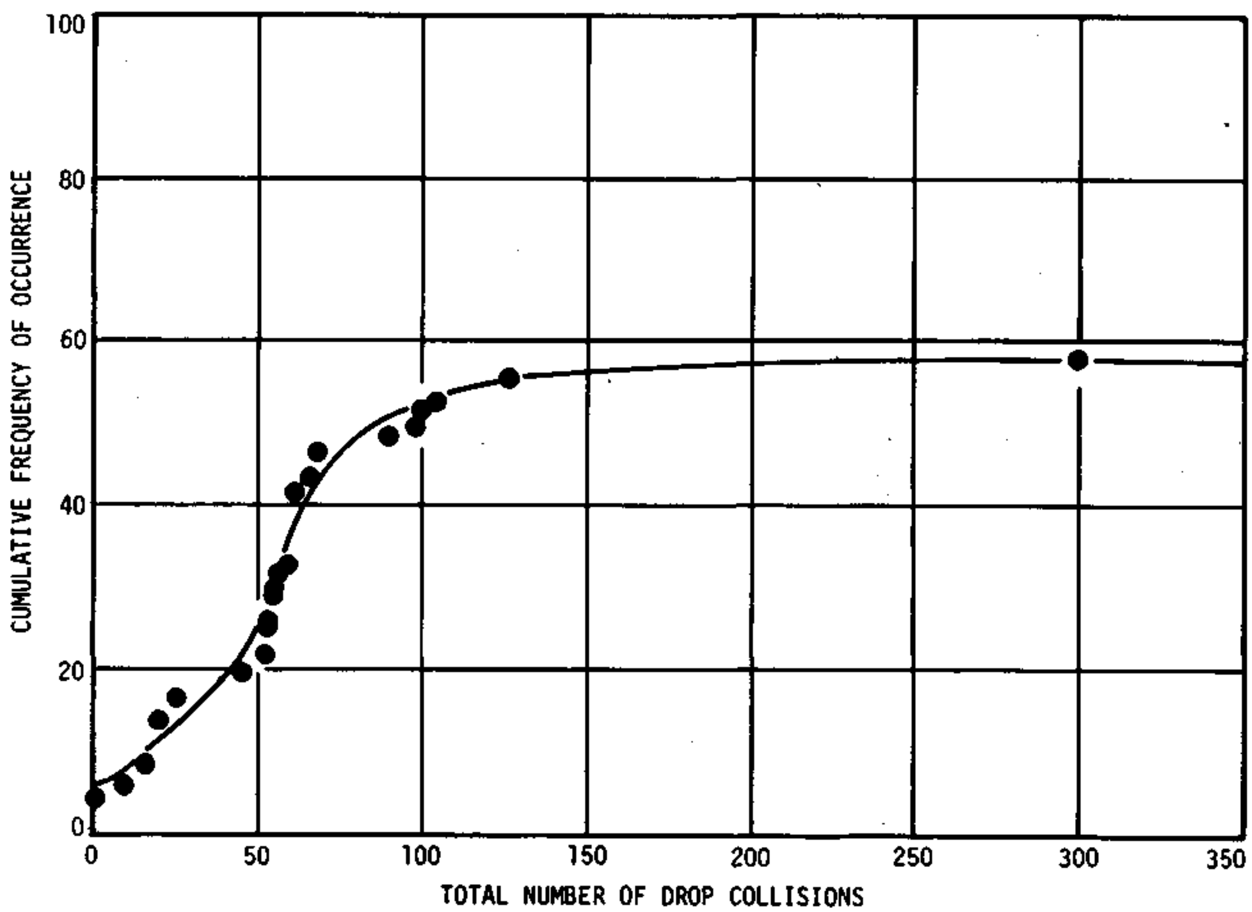

Figure 19. Cumulative frequency of rounds into impact area as a function of total number of drop collisions

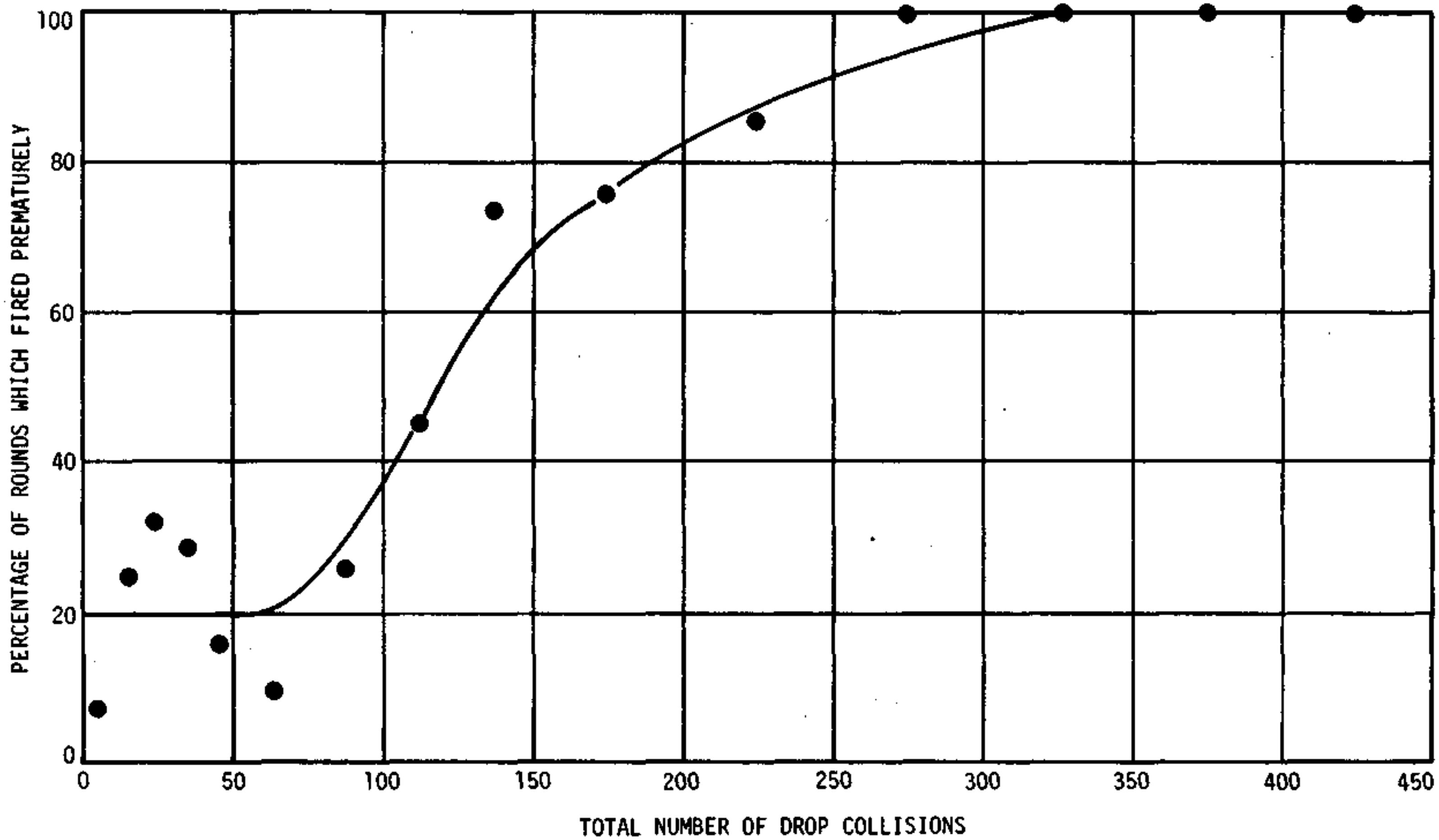

Figure 20. Probability of premature firing as a function of expected number of drop collisions

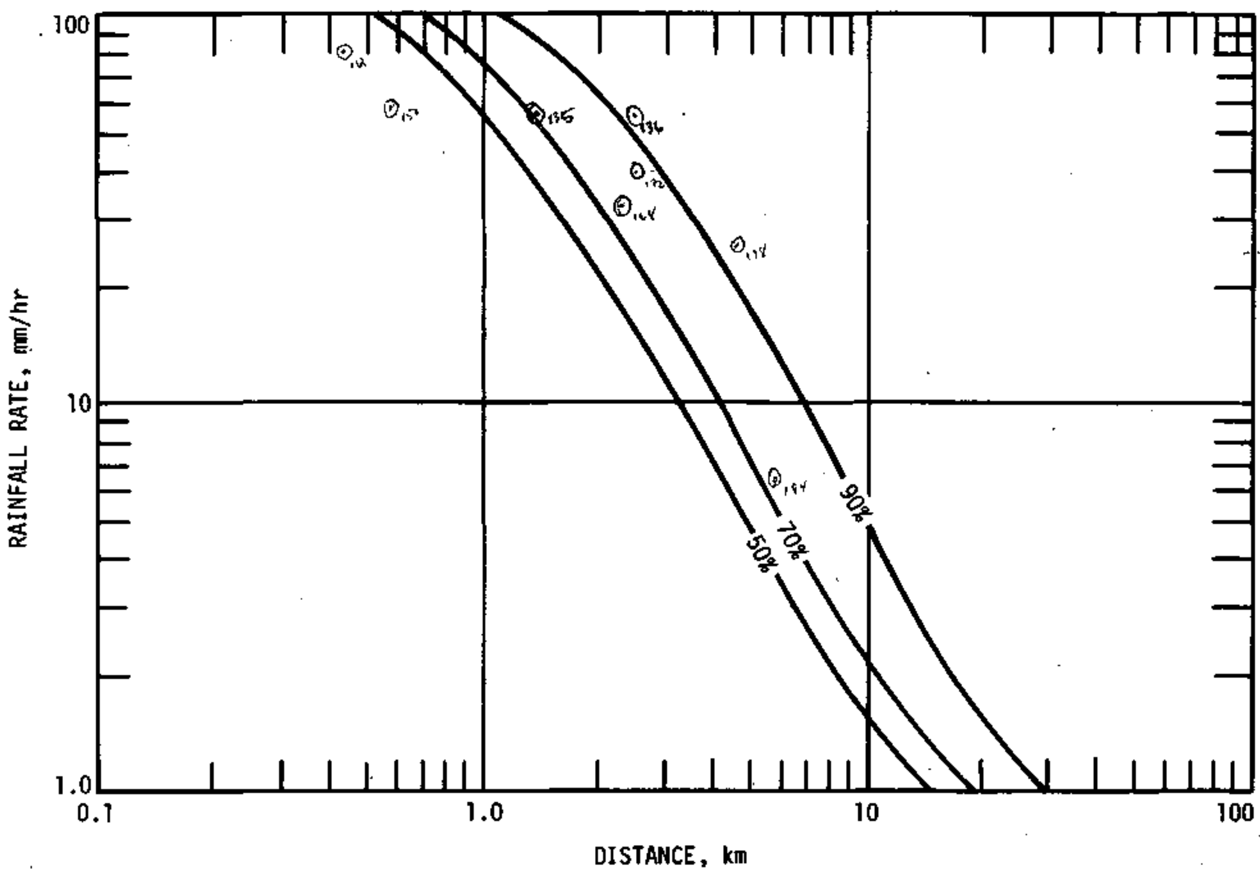

Figure 21. Probable distance to premature detonation as a function of rainfall rate (predicated on total number of drop encounters)

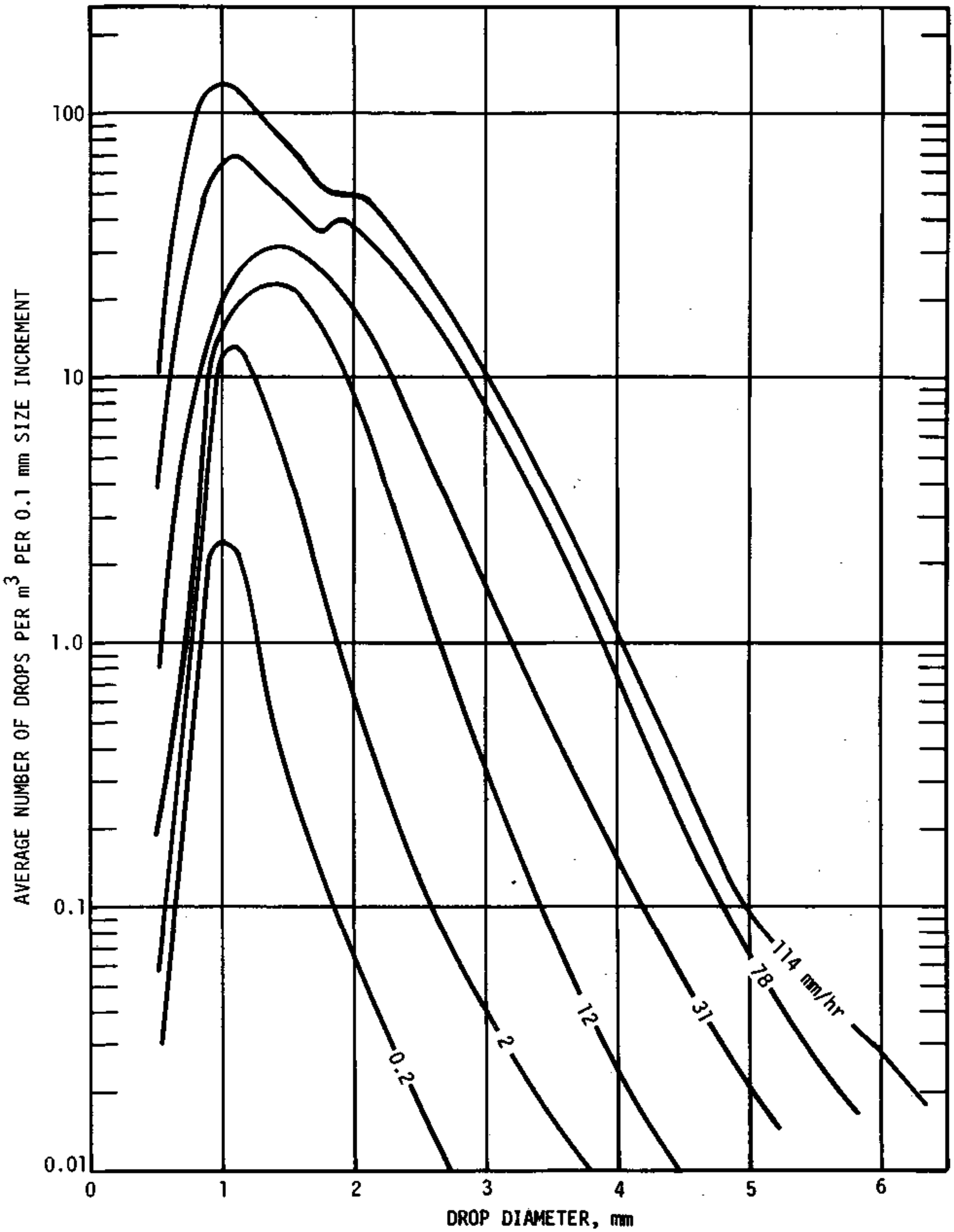

Figure 22. Average raindrop distributions for data taken at the Pina Range, Canal Zone, June 27 to July 19, 1968